Vol. 67 No. 4

JOURNAL

of the

AMERICAN SOCIETY

of

NAVAL ENGINEERS Inc.

NOVEMBER, 1955

PUBLISHED QUARTERLY BY THE SOCIETY TO FURTHER THE ADVANCEMENT OF NAVAL ENGINEERING.

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VOL. 67 NOVEMBER, 1955 No. 4

Published Quarterly at Washington, D. C., by The American Society of Naval Engineers, Inc.

Entered as Second Class Matter at the Post Office at Washington, D. C., and at Nashville, Tenn. Acceptance for mailing at special rate of postage provided for in Section 1103. Act of October 3, 1917, authorized on July 3, 1918.

Subscription Rates for Non-Members

The subscription price of the JOURNAL, postpaid to points in the United States and possesions is $9.00. Single copies, $2.25. To other countries, $20.00. Single copies, $5.00. All subscriptions payable in advance.

Make checks, drafts and postal money orders payable to THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Advertising rates will be furnished on application.

Addresses will be changed at any time, but only upon notification. Immediate notice should be given of any delay in the receipt of the JOURNAL.

Address all communications for the Society to

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.
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Washington 4, D. C.

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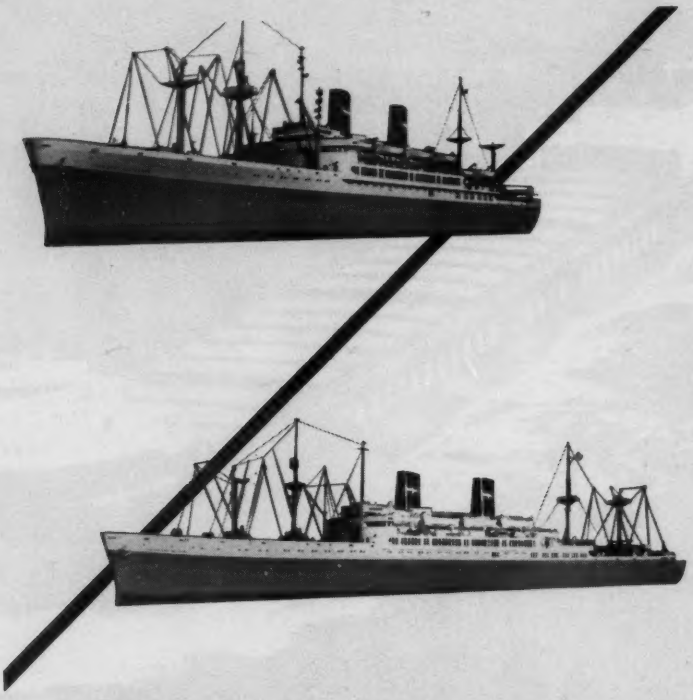

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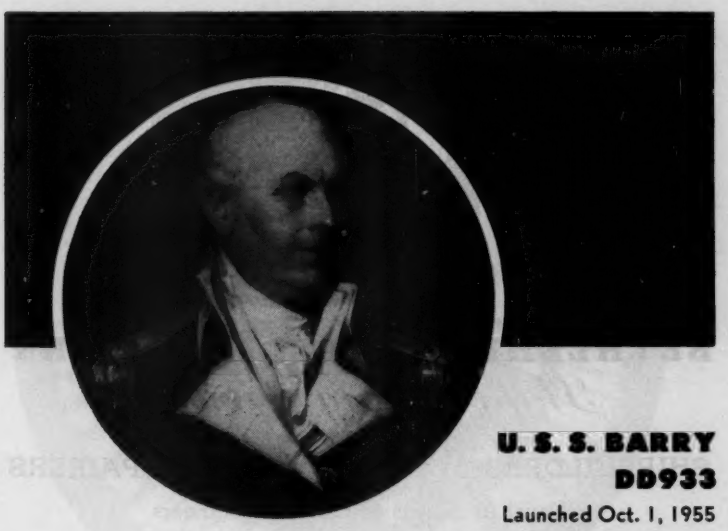

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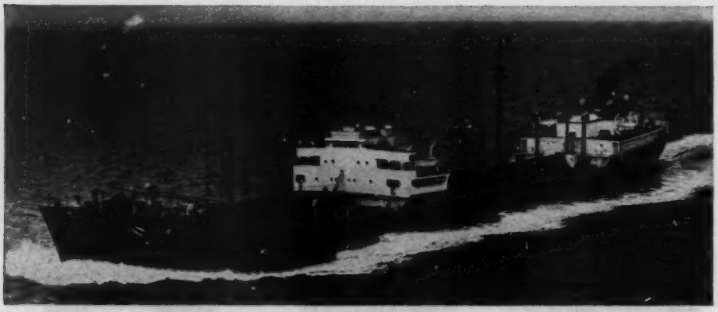

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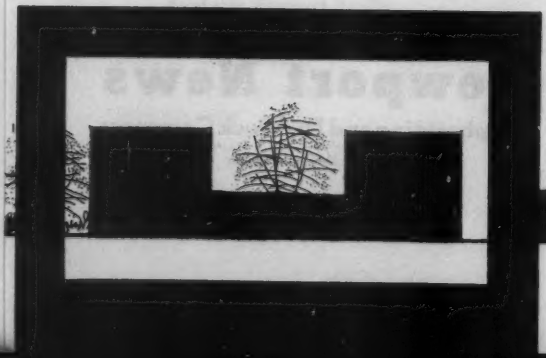

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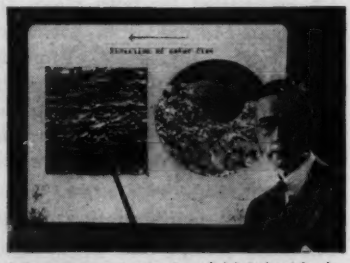

Left, impingement corrosion of Admiralty tube by high velocity sea water with air bubbles. Right, section through part of horseshoe-shaped pit.

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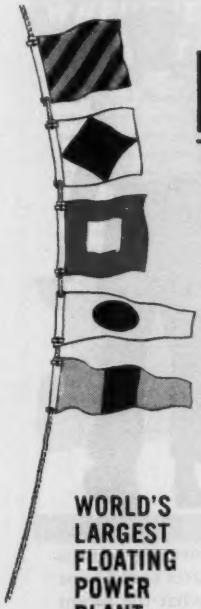

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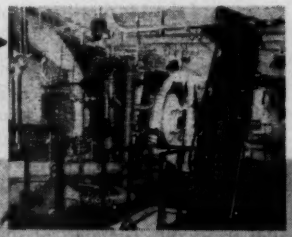
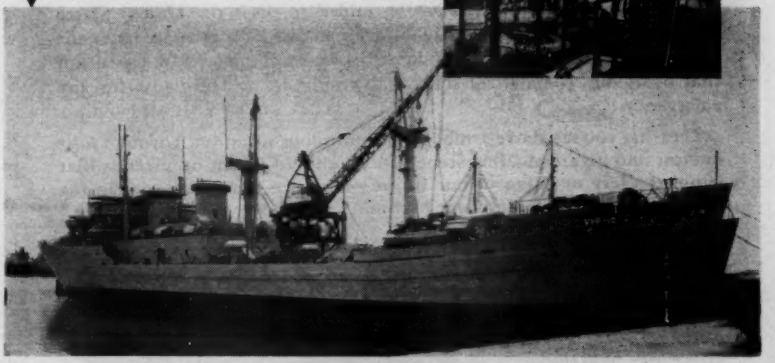


U. S. Navy YFP-10, turbo-electric generating plant, capable of delivering 34,000 kw at 13,000 v. Built for the Bureau of Yards and Docks by the Gibbs Corporation, Jacksonville, Fla. Power plant designed by Reynolds, Smith and Hills, Engineers, Jacksonville, Fla. ▼



FOSTER WHEELER

The "ways & means" committee is back in session

This is probably one of the healthiest scenes that anyone interested in the welfare of the United States could hope to see. It's a symbol, to begin with, of what the recent passage of the 124.6 million dollar Ship Fund Bill means to our national maritime industry.

It's much more than men going back to work; it's a *movement toward U. S. preparedness and prestige.* These men, and thousands like them, soon will be engaged in adding to one of America's most vital peacetime agencies and wartime defense arms—the Merchant Marine. And, right now, if anything needs to be added to, it is the United States Merchant Marine. This kind of awareness can help take us from the *number seven* position in ship construction in the world to a position that befits our commercial status and results in our readiness for any emergency.

Let what you see above symbolize a continuous situation. Through *your* interest and awareness this scene can be, should be, an occurrence that happens every morning of our future—until we can safely answer the question, "How's the Merchant Marine?," with "Big, strong and ready."

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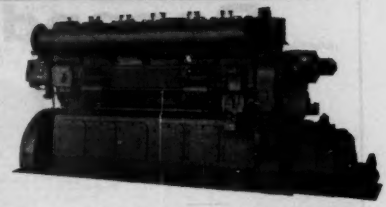

truly advanced engineering, has enabled Cooper-Bessemer Diesels to do a notable job in Navy and Coast Guard vessels from the biggest combat ships to relatively small patrol boats. Yes, you can always count on Cooper-Bessemers for Diesel performance at its finest.

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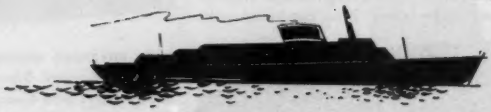

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main propulsion units power the new United States Navy destroyer escorts

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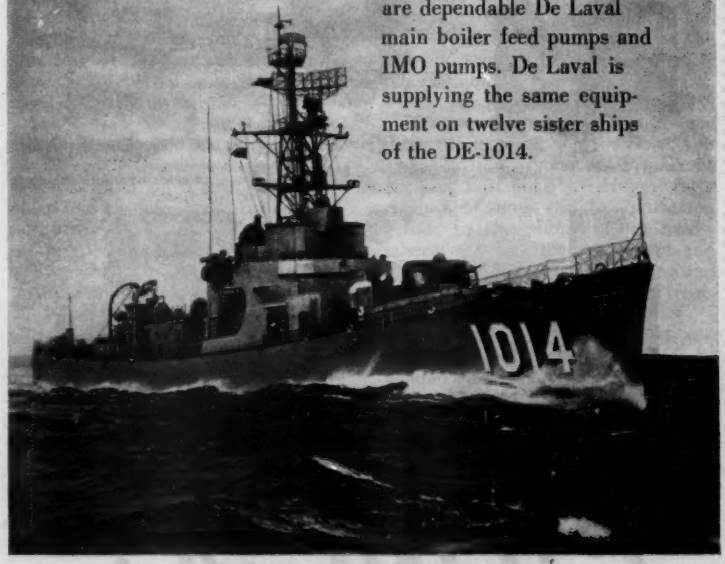

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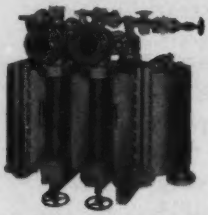
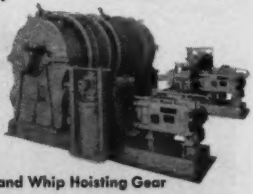


Tubejet Steam Jet Air Ejector

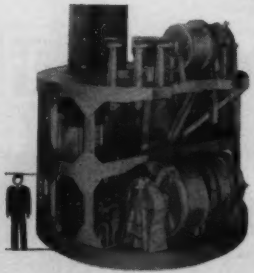
Electric Warping Capstan

Electric Hydraulic Windlass

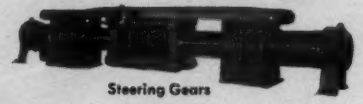
Warping Winch



Boat Crane and Whip Hoisting Gear



Boat and Airplane Crane



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"T-1" enables you to reduce the size and weight of heavily stressed or heavily abused parts with no sacrifice in service life or dependability.

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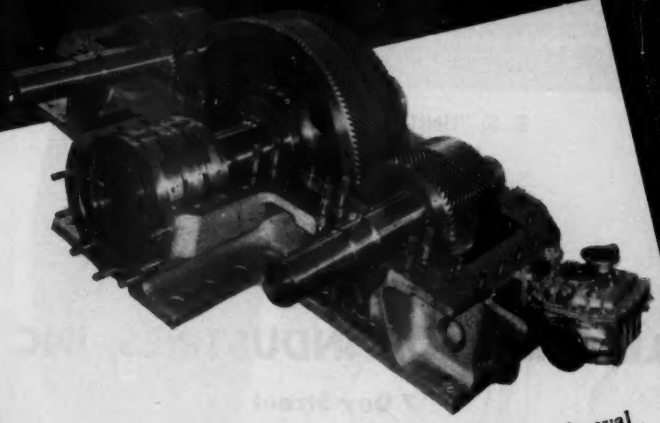

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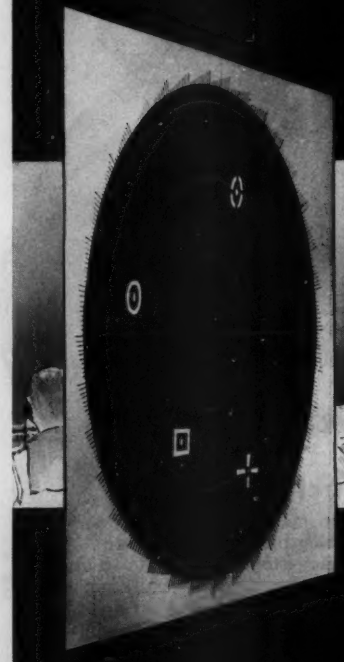
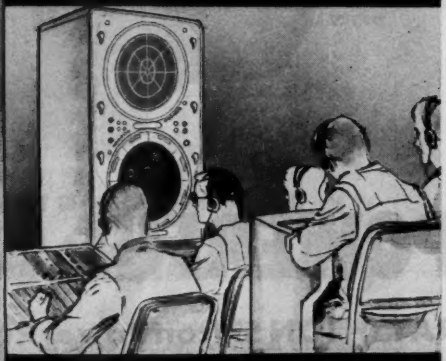
When the Navy's new Mark 6 Target Designation System "sights" an enemy, the range and bearing data are automatically transmitted to appropriate gun directors. Guns are "on target" before the flying object gets within maximum effective range. The result may well spell the difference between survival and disaster for ship and crew.





Developed by RCA in close coordination with Naval personnel, the Mark 6 Target Designation System is now in full production. It is but one of the many complete electronic systems which RCA has developed for the armed forces. RCA engineering — from original planning to final production — assures greater efficiency, effectiveness and safety in operation.

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JOURNAL

OF

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Vol. 67 NOVEMBER, 1955 No. 4

Statements contained in articles herein are the private opinions and assertions of the writers and should therefore not be construed as reflecting the views of The American Society of Naval Engineers, Inc., nor of any other organization with which such writers are affiliated.

The Society as a body is not responsible for statements made by individual members

COUNCIL OF THE SOCIETY

(Under whose supervision this number is published)

Rear Admiral F. R. Furth, U.S.N., President

Captain Rawson Bennett, U.S.N.
Commander W. D. Brinckloe, U.S.N.
Commander C. H. Campbell, U.S.N.R.
Rear Admiral R. E. Cronin, U.S.N.
Captain J. M. Farrin, U.S.N.
Mr. John F. Hanlon
Mr. James S. Melton
Commander J. W. Naab, U.S.C.G.
Lieut. Comdr. J. W. Sawyer, U.S.N.R.

Captain J. E. Hamilton, U.S.N., (Ret.), Secretary-Treasurer

SECRETARY'S NOTES

Annual Election:

Ballots have been mailed for the election of Officers for 1956 and for Members of the Council for 1956-57. The following terms of office will expire on 31 December 1955:

President.....Rear Admiral F. R. Furth, U.S.N.

Secretary-Treasurer.....Captain J. E. Hamilton, U.S.N., Retired

Council Members:

Regular Navy.....Captain J. M. Farrin, U.S.N., and Commander W. D. Brinckloe, U.S.N.

Naval Reserve.....Commander C. H. Campbell, U.S.N.R.

Coast Guard.....Commander J. W. Naab, U.S.C.G.

Civilian.....Mr. John F. Hanlon

A nominating committee composed of Vice Admiral R. E. McShane, USN, Retired as Chairman and Captains Bennett and Farrin, Commanders Naab and Campbell and Mr. Hanlon named the following candidates. This slate was approved at the Annual Meeting on 4 October 1955:

For President.....Rear Admiral K. K. Cowart, USCG
For Secretary-Treasurer....Captain J. E. Hamilton, USN, Retired
Captain W. R. Millis, USN, Retired

For the Council:

Regular Navy:	Captain W. I. Bull, USN Captain J. M. Farrin, USN Rear Admiral L. V. Honsinger, USN Captain Peter Horn, USN
Naval Reserve:	Commander C. H. Campbell, USNR Commander E. G. Kintner, USNR
Coast Guard:	Captain Richard D. Schmidtman, USCG Captain Peter V. Colmar, USCG
Civilian:	Mr. Thomas B. Shepard, Jr., General Electric Co. Mr. F. J. Lindauer, Fairbanks Morse & Co.

The ballot, in addition will carry the names of three members who have been nominated with the unanimous approval of the Council for election as Honorary Cembers. They are: Mr. A. G. Fessenden, Mr. E. C. Magdeburger and Mr. K. D. Williams. Unfortunately Mr. Magdeburger's death which is announced elsewhere in this issue deprives the Society of his continued active membership. If he is elected to Honorary Membership, a posthumous award will be made to Mrs. Magdeburger.

Also on the ballot is the previously announced change in the by-laws which, if approved, will make the appointed members of the Department of Defense Secretariat, ex-officio Honorary members of the Society.

Annual Banquet

A printed announcement of the change in location of the Annual Banquet in 1956 was mailed with the ballots. Since the location has been fixed for so many years, it was considered that members should be advised of the change as soon as possible.

The 1956 Annual Banquet will be held on Friday, April 27, 1956 at the Sheraton-Park Hotel which is on Woodley Road at Connecticut Ave., N.W., Washington 8, D.C. The reason for the change is that the Sheraton-Park has built and put into operation, Sheraton Hall which has sufficient capacity to hold our banquet in a single room. As nearly as is practicable, all other features of the affair will be maintained at the same standards as in past years.

Society Office

Prior to 1 January 1956, the officers of the Society will be moved to 1012 14th Street, N.W. in Washington, D.C.

THE JOURNAL

The Council has decided to change the page size of the JOURNAL. Beginning with the February 1956 issue the JOURNAL will be 8¼ by 11¼ inches. Various arrangements will be tried during 1956 to arrive at the best standard for the future. This change is believed to be desirable because of the increased thickness and to improve readability. Comments will be solicited during the year.

ERRATA

On page 698 in the August issue of the JOURNAL an equation contained the term $(P - \phi^2)$. This correctly should be

$$(P - \phi)^2$$

THE MONITOR HISTORICAL SOCIETY, INC.

The USS *Monitor* has a particular place in the history of Naval Engineering as well as in the more dramatic role which she played on 8 March 1862. An organization has been formed to locate and salvage the remains of the *Monitor*. That Society has published the following statement which may be of interest to members of this Society:

On Sunday, March 9, 1862, news came to the Navy Department that sent Secretary Welles hurrying to President Lincoln. Moving out from Norfolk on Saturday afternoon, the Confederate ironclad *Virginia*, popularly known by its former name of *Merrimac*, had met in battle two Union war vessels, the *Cumberland* and the *Congress*, ramming and sinking the one and firing and destroying the other. Only lack of time prevented the destruction of a third, the *Minnesota*. It was known that the *Virginia* would return to the scene to complete the work of destruction and then, perhaps, threaten to move up the Potomac, disperse Congress, and destroy the capital. Washington was in a panic.

News that the South had raised the sunken Union war vessel *Merrimac*, and was converting it into the ironclad *Virginia*, was the sole reason for the building of the *Monitor* by John Ericsson. It was a construction race between the North and the South, and the *Monitor* was launched, thanks to the genius of American industry, only one hundred days after laying the keel. So great was the need for haste that the *Monitor* put to sea with very little testing and arrived at Hampton Roads on the evening of March 8, 1862.

At daylight on March 9 the grim and battle-tested *Merrimac* was seen steaming toward the *Minnesota*, determined to complete the destruction of the Union fleet and lift the blockade. As she came on, the *Monitor* made straight for her, a David against a Goliath, ten guns on the *Merrimac* against two on the *Monitor*.

After three hours firing at point blank range, it was a drawn battle. This meeting of the ironclads, each impenetrable to the projectiles of the other, proved conclusively that wooden ships were to be of very limited use in future naval warfare. The great navies, which France and Great Britain had built at such immense cost, were comparatively ineffective. The *Monitor* had saved the Union fleet and preserved the blockade.

The career of the *Monitor* afloat lasted only eleven months, for she foundered in a storm off Cape Hatteras, North Carolina, while in tow of the *U.S.S. Rhode Island*, in the early morning of December 31, 1862, with the loss of sixteen of her officers and crew.

The Monitor Historical Society, Incorporated, a non-profit organization formed in the District of Columbia, was founded for the purpose of bringing together people with a common goal—to locate, salvage, and establish as a *National Shrine*, this historic ship, which not only helped turn the tide of war and preserve the Union, but was responsible, more than any other ship, for a radical change in the entire concept of naval warfare.

For the past two years the Monitor Historical Society, with the co-operation of the Department of the Navy and the Naval Historical Society, has conducted extensive research as to the location, condition, and method of salvage of the *Monitor*.

To locate this famous ship is a challenging and hazardous undertaking, and calls for community effort. The Society, before undertaking its second search, is endeavoring to defray part of the cost by increasing its membership. It has no salaried officers. All that has been accomplished to date, including an extensive search of the Hatteras area by ship and plane in May of 1954, has been due to Raynor T. McMullen of Dundee, Michigan, a retired Postal employee and Founder and President of the Society.

The crew of the *Monitor* were hand-picked volunteers. Once again the *Monitor* is calling for volunteers, not to man its guns, but to wrest it from the ocean bottom and restore it to its rightful place in the hearts of all Americans.

You may help by mailing your contribution today to The Monitor Historical Society, 1764 K St., N.W., Washington 6, D. C.

Security Clearance of Articles Published In the Journal

The Society has no facilities for obtaining Department of Defense Security clearance for any articles which are written by individuals who are in any way subject to Defense Department regulations. It is incumbent, for his own protection, that each author obtain the necessary clearance, using facilities appropriate to his position, before submitting an article to the Society.

Engineering Foundation Grants Advance Varied Projects

Engineering Foundation, which administers the income from a $1,500,000 fund dedicated to the stimulation of engineering research, has now made available its allocations for the 1955-1956 fiscal year. Although this income of about $50,000 seems very modest in comparison with the present-day scale of research expenditures, it has served to nurture in their early stages many research programs which have ultimately attracted large-scale financial support from other sources and become projects of major import.

This year's grants total $61,850. They will advance twenty-six projects, which are receiving estimated outside support of $426,000. The projects, which cover a wide range of research, are being carried out in university laboratories all over the country under sponsorship of the major engineering societies.

An important project receiving one of the grants is a study of the Properties of Steam, which is being sponsored by the American Society of Mechanical Engineers. The Steam Properties Research Program, which was established at the Fourth International Steam Tables Conference in Philadelphia in September 1954, revives an earlier ASME program that was completed in 1934. The extremely high pressures and temperatures commonly used today in both steam power generation and chemical processing emphasize the need for extending the present working steam tables that have been in use since 1934. As a first step, the research program will try to obtain experimental data for extending the steam table range to 1500°F and 15,000 psia. It will function within an international framework.

Of much significance also is a joint program of the American Society of Mechanical Engineers and the American Society for Testing Materials on the Effect of Temperature on the Properties of Metals. In the thirty-one years of its existence this joint project has done a tremendous job in devising reliable methods of testing metals at high and low temperatures and in determining the effect of these temperatures on the strength properties of a wide variety of metallic materials, especially steel.

The decline in the cost of electric power in the past decade of steadily rising prices is due in large part to studies by turbine and steam generator manufacturers and power generating companies, which have made it possible for central station generating plants to improve their efficiency by the use of increasingly higher steam temperatures and pressures. Receiving the support of these groups as well as of Engineering Foundation is an ASME-supported program on High-Temperature Steam Generation. This ASME project—begun in 1932, dropped during the war, and reestablished in 1949—is attempting to lower electric power costs still further by studying the possibility of using a regenerative steam cycle at temperatures up to 1650°F. Of particular concern to this group are the severe corrosive action of high-temperature steam and the lack of metallurgical stability of the materials available for superheater tubing. New tests will be made at the Philip Sporn Plant of the American Gas and Electric Company, where steam is available at 1000°F temperature and 2000-psi pressure. For these tests special apparatus has been designed in cooperation with the U. S. Navy Bureau of Ships.

A reduction in the cost of reinforced concrete construction and the use of longer concrete spans than are now permissible may be ultimate benefits of another project, the Reinforced Concrete Research Council, which was established in 1948 under sponsorship of the American Society of Civil Engineers. This project began with a

critical reexamination of the empirical basis for the design of reinforced concrete structures, which has been in use for many years, with the idea of developing a workable scientific theory for such design to replace the old empirical methods. The research, involving extensive testing of reinforced concrete members under a wide variety of conditions of load, stress, and exposure, is currently under way at the University of Illinois, Virginia Polytechnic Institute, Lehigh University, and Syracuse University.

The Council on Wave Research, an independent research program set up to survey the various phases of water-wave action in order to determine the fields in which information is lacking, continues to receive Engineering Foundation support. In the past five years the Council has brought together workers in the field of wave research and related activities in five Conferences on Coastal Engineering and one Conference on Ships and Waves. On October 31 and November 1 and 2 of this year it is sponsoring a Conference on Coastal Engineering Instruments at its headquarters at the University of California, Berkeley. The forthcoming conference will be devoted to summarizing the various types of oceanographic instruments of value to engineers.

A three-year research project on the Thermal Resistivity of Soils —cosponsored by the American Institute of Electrical Engineers, Engineering Foundation, and various other groups—is beginning at Princeton University. This project was authorized to study the heat-dissipation characteristics of various soil types, because of the importance of such information in determining the load-carrying capacity of underground cable systems and in many other fields of engineering. It will cover such factors as effect of soil solids content, critical heat rate, critical temperature gradients, moisture migration effects, and rewetting characteristics of clays.

Grants are also being made to eight projects under sponsorship of the American Institute of Mining and Metallurgical Engineers. These AIME projects include a newly instituted program for predicting disastrous Storm Surges, which is getting under way at Columbia University's Lamont Laboratories at Palisades, N. Y.

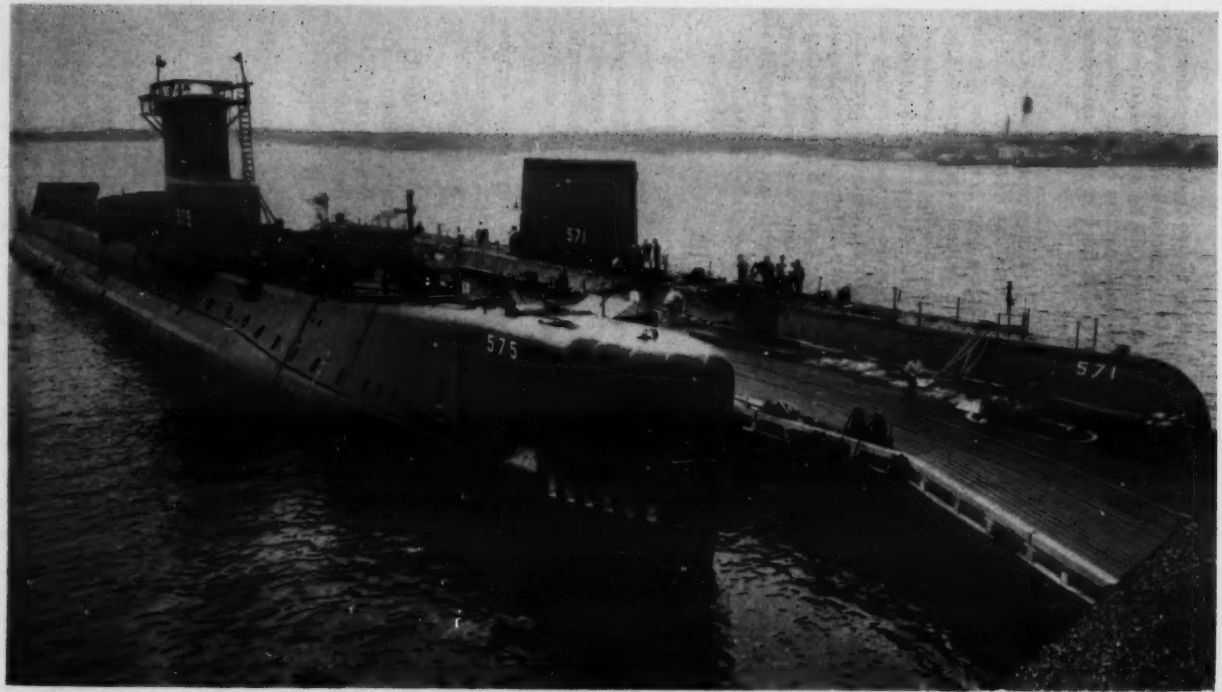
Discussion

The following discussion was received in a letter from Captain H. P. Webster, U.S.N. Captain Webster was a member of the Council until his transfer to the Netherlands in June of this year.

"The article by Johnson and Sawyer on plastic reduction gear covers was most interesting to me. I would like to comment, however, on two areas of this article. In the first case I note that the laboratory test requirements of a plastic cover are primarily gauged at using the characteristics of the steel cover to insure that the plastic cover is good enough. In my opinion, no investigation has been

made of the steel cover characteristics to insure that their performance is not in excess of that required for practical purpoes. I would suggest that the principles of value engineering be utilized to make this determination and possibly the specifications can be reduced and a satisfactory plastic cover obtained at far less cost than is now the case.

Another area of the article to which I take exception is the lack of emphasis given to noise reduction resulting from the use of a plastic cover. As is admitted in the article a noise reduction of from 5 to 8 decibels is obtained. This is not a reduction which should be overlooked. We must remember that when dealing with decibels we are dealing in a logarithmic function and a reduction of 8 decibels is a tremendous reduction in sound pressure. I read an article in *Fortune* magazine last month which outlined industrial noise and gave a very clear picture of sound pressure versus decibels. If you will look at this article you can readily see that an 8 decibel reduction in noise level is most meaningful and something which, in my opinion, far outweighs the reduction in weight, use of non-critical materials, and reduction in cost."



USS *NAUTILUS* AND USS *SEAWOLF*

Official U.S. Navy Photograph

AN INTRODUCTION TO REACTOR PHYSICS

GEORGE LEPPERT

THE AUTHOR

was born in 1924 and graduated from the University of Wisconsin in 1947. He served in the United States Navy from 1943 to 1946 and is a qualified submarine officer. He received the M.S. (1952) and Ph.D. (1954) degrees in Mechanical Engineering from Illinois Institute of Technology and was engaged in the Reactor Engineering Division of Argonne National Laboratory from 1950 to 1953. Since 1954, he has been in the Department of Mechanical Engineering of Stanford University, teaching courses in heat power and nuclear engineering and conducting research in reactor heat transfer.

The utilization of energy from nuclear fission in engineering systems is so recent that few persons who are not themselves engaged in the nuclear program have an understanding of the phenomena involved. This is true even of competent engineers engaged in technical work and of recent engineering graduates, many of whom will sooner or later become involved in some aspect of the rapidly expanding nuclear industry.

An article by E. C. Pigott which was recently reprinted in this Journal* traced the evolution of knowledge concerning atomic energy from the days of ancient Greece to the present time. It is the intention of the present paper to review the physical principles which are necessary to an understanding of nuclear reactor design theory, elaborating on Pigott's discussion where necessary. A subsequent paper will review the reactor theory which leads to design calculations. A further intention is to provide adequate literature references for the worker whose interest carries him beyond the introductory material herein presented.

*Pigott, E. C., Murex Review, Vol. 1, No. 14, 1954. Reprinted in J. Amer. Soc. Naval Engrs., Vol. 67, No. 2, 1955, p. 375.

TABLE I.

ELEMENTARY PARTICLES

PROTON. Nucleus of the hydrogen atom, having unit positive charge (4.80×10^{-10} esu) and a mass of 1.00758 amu.

NEUTRON. Uncharged particle having mass of 1.00897 amu, just slightly greater than the proton. The neutron is unstable with a half-life of about 20 or 30 minutes and decays into a proton and an electron.

DEUTERON. Nucleus of "heavy hydrogen," composed of a proton and a neutron, tightly bound by nuclear forces. The deuteron has the unit positive charge of the proton and a mass of 2.01472 amu.

ALPHA. Nucleus of a helium atom, consisting of two protons and two neutrons, tightly bound. The alpha particle has a double positive charge and a mass of 4.00391 amu.

ELECTRON (negative). A particle of unit negative charge and rest mass only 1/1840 that of the proton. Frequently called a *beta particle.*

POSITRON. An electron with unit positive charge. The positive electron has a very short life since it combines readily with a negative electron to form two gamma quanta *(annihilation radiation).*

GAMMA. Electromagnetic radiation without rest mass or electric charge. The behavior of gamma rays can sometimes be explained only by supposing them to be equivalent to particles of energy $h\nu$, where ν is the frequency in cycles per second and h is Planck's constant, 6.62×10^{-27} erg-sec.

NEUTRINO. A particle which has not yet been directly observed but which is postulated to explain the energy spectrum of beta particles. It has zero rest mass and no electric charge.

THE ATOM

Rutherford-Bohr Model

The concept of the atom proposed by Rutherford and developed by Bohr and Sommerfeld is that of a dense central portion, the *nucleus*, in which is concentrated the positive charge which varies in magnitude for the various elements. Electrons, each with unit negative charge and with rest mass almost negligible compared to that of the nucleus, move in circular or elliptical orbits about this central core. An orbit is characterized by the energy of its electron, and the various stable orbits are referred to as "stationary states." The possible stationary states are definitely limited in number, with each permissible state described by its quantum numbers. Although this model is no longer completely valid in the light of the more recent wave mechanics, it is extremely useful for many purposes and will be used in the discussion which follows.

Starting with the simplest possible element, hydrogen, we recall that the nucleus consists of a single proton (Figure 1), so that both the mass number (A) and the atomic number (Z) are unity. For the electrically neutral atom, there is one electron in the first permissible shell (K-shell). Hydrogen is the only element for which the mass number and the atomic number are equal, however, since all other nuclei contain neutrons as well as protons. Helium, with two neutrons and two protons in the nucleus, requires two orbital electrons which fill the K-shell and produce an element which is chemically inert. The other inert gases

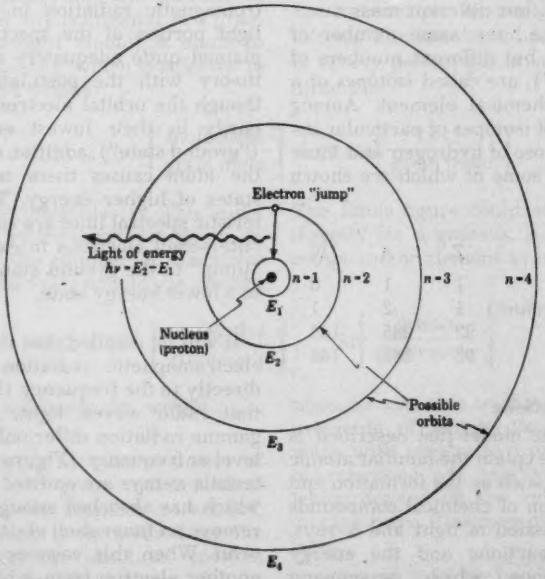


Figure 1. Electron orbits in Bohr's model of the hydrogen atom. (Reprinted with permission from *Introduction to Nuclear Engineering* by R. L. Murray, 1954, Prentice-Hall, Inc.)

—neon, argon, krypton, etc.—also occur when the highest quantum level is filled for the particular atom in question.

Periodic System

The family of chemical elements as we know them is built up of nuclei of different numbers of protons and neutrons, together with orbital electrons of various energies. The chemical nature of an element is determined by its atomic number, and if the elements are arranged in order of increasing Z and grouped according to the repetition of physical and chemical properties, the familiar *periodic table* of the elements is obtained.

It is found that changing the number of neutrons in the nucleus does not change the chemical behavior of an element. Nuclei of the same atomic number (Z), but different mass numbers (A), i.e., the same number of protons (Z) but different numbers of neutrons (N), are called *isotopes* of a particular chemical element. Among the groups of isotopes of particular interest are those of hydrogen and those of uranium, some of which are shown below:

Symbol	Z	A	N
H^1	1	1	0
H^2 (deuterium)	1	2	1
U^{235}	92	235	143
U^{238}	92	238	146

Atomic Reactions

The atomic model just described is adequate to explain the familiar atomic phenomena, such as the formation and decomposition of chemical compounds and the emission of light and x-rays. Chemical reactions and the energy transformations which accompany them are the result of interactions between the outermost (unfilled) orbital electron shells.

The neutral oxygen atom, with eight protons and eight neutrons in the nucleus, has two electrons in the K-shell and six in the L-shell. Because the L-shell requires eight electrons for completion, oxygen is said to have a valence of minus two and is able, for example, to combine chemically with an atom of magnesium, which has two electrons in the K-shell, eight in the L-shell, and two in the M-shell. Because these latter two electrons are part of an uncompleted shell, they readily fill the uncompleted L-shell of the oxygen atom, as would those of any other element with a plus two valence. We can visualize all such chemical reactions as taking place by a sharing of outer shell electrons with an accompanying release or absorption of energy.

The emission of characteristic electromagnetic radiation in the visible light portion of the spectrum is explained quite adequately in the Bohr theory with the postulate that, although the orbital electrons are ordinarily in their lowest energy state ("ground state"), addition of energy to the atom causes them to pass into states of higher energy. The characteristic spectral lines are emitted when outer-shell electrons in excited states "jump" to the ground state or at least to a lower energy state.

It will be recalled that the energy of electromagnetic radiation is related directly to the frequency ($E=h\nu$), and that radio waves, light, x-rays and gamma radiation differ only in energy level or frequency (Figure 2). Characteristic x-rays are emitted by an atom which has absorbed enough energy to remove an inner shell electron from its orbit. When this vacancy is filled by another electron from a higher quantum level, an x-ray characteristic of the element and of the levels involved is emitted.

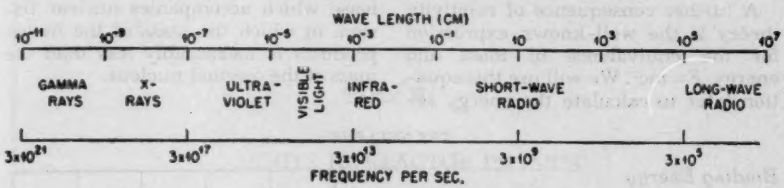


Figure 2. Approximate wave length and frequency region of various electromagnetic radiations. (Reprinted with permission from *Sourcebook of Atomic Energy* by S. Glasstone, 1950, D. Van Nostrand Co.)

Avagadro's Number

The number of atoms in a gram atomic weight of any substance is 6.023×10^{23}. This fact from atomic theory is useful in computations where it is desried to interpret information about an atom of an element (or its nucleus) in terms of a macroscopic sample of the element. It is equally true, of course, that the number of molecules of any compound in a gram molecular weight (mole) is equal to this same number, which is referred to as *Avagadro's number.*

Furthermore, it is known that one mole of any perfect gas occupies 22.4 liters at standard conditions (O°C and standard atmospheric pressure). Since most real gases follow this behavior rather closely under conditions of interest to reactor design, it is possible to calculate certain macroscopic properties of gases in terms of volume when the microscopic or nuclear data are known. The number of molecules per cc of any perfect gas at standard conditions is

$$6.023 \times 10^{23} \left[\frac{\text{molecules}}{\text{gram mole}}\right] \Big/ 22{,}400 \left[\frac{\text{cc}}{\text{gram mole}}\right]$$

or 2.68×10^{19} molecules/cc. This number divided by the density in grams/cc would give the number of molecules per gram of a macroscopic gas sample. The latter figure could also be found directly for a gaseous, liquid or solid compound or element as follows:

$$6.023 \times 10^{23} \left[\frac{\text{molecules}}{\text{gram mole}}\right] \Big/ \text{M} \left[\frac{\text{grams}}{\text{gram mole}}\right]$$

where M is the molecular weight.

Relativity

In developing his special theory of relativity, the great mathematical physicist Albert Einstein postulated, first, that there is no method for the determination of "absolute" motion, and, second, that the velocity of light is constant regardless of the frame of reference of the source or the observer. As a consequence of these assumptions, he was able to show that measurements of length, time and mass made with respect to a moving frame of reference are relative quantities which depend on the velocity of the moving body. The mass of such a body is

$$m = m_o / \sqrt{1 - v^2/c^2}$$

where m_o is the "rest mass"—i.e., the mass of the body measured at zero velocity.

A further consequence of relativity theory is the well-known expression for the equivalence of mass and energy, $E=mc^2$. We will use this equation later to calculate the energy release which accompanies nuclear fission, in which the mass of the fission products is measurably less than the mass of the original nucleus.

THE NUCLEUS

Binding Energy

The protons and neutrons of which all nuclei are now believed to be composed are held together by powerful but very short-range attractive forces. At other than very close range, coulomb repulsion dominates as the force between the positively charged protons. As the mass number increases, relatively more neutrons compared to the number of protons are required for nuclear stability. Figure 3 shows the variation of the number of neutrons with the number of protons for stable nuclei, from ordinary hydrogen which has zero neutrons and one proton to U^{238} with 146 neutrons and 92 protons.

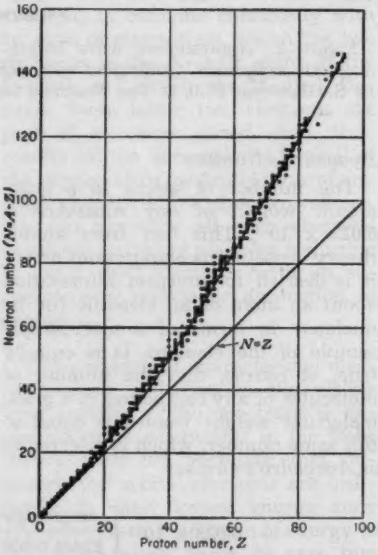


Figure 3. Neutron-proton plot of stable nuclides (includes radionuclides with half lives greater than 1,000 years). (Reprinted with permission from *Introduction to Nuclear Engineering* by R. Stephenson, 1954, McGraw-Hill Book Co., Inc.)

Based on the physical atomic weight scale, in which an atomic mass unit (amu) is arbitrarily defined as 1/16.00000 times the mass of a neutral 0^{16} atom, the masses of the atomic particles have been accurately determined as follows:

neutron	:	1.00897 amu
proton	:	1.00758 amu
electron	:	0.00055 amu

The amu is equivalent to 1.66×10^{-24} gram or, from the equation $E=mc^2$, to 1.49×10^{-3} erg or 931 mev.

Armed with these measurements, we should be able to predict the mass of any atom whose mass number and charge we know. It would seem that the atomic weight of 0^{16}, for example, should be:

8 neutrons $=8 \times 1.00897=8.07176$ amu
8 protons $=8 \times 1.00758=8.06064$ amu
8 electrons $=8 \times 0.00055=0.00440$ amu

Total mass of constituents $=16.13680$ amu

This discrepancy of 0.13680 amu is called the *mass defect*, and its equivalent of 127.4 mev is the *binding energy* of the 0^{16} nucleus. It is this amount of energy which would have to be supplied to permit the particles of which the nucleus is composed to exist separately.

TABLE II.

UNITS IN REACTOR PHYSICS

Energy and Mass

Electron-volt (ev.): the energy acquired by a particle of unit charge when it is accelerated through a potential of one volt.
1 ev $= 1.6 \times 10^{-12}$ erg.

Million electron volts (mev.): one million times as large as the electron volt, the mev is the common energy unit in nuclear physics.
1 mev $= 1.6 \times 10^{-6}$ erg.

Atomic mass unit (amu): 1/16.00000 times the mass of a neutral O^{16} atom.
The equivalence in energy of 1 amu is 931 mev. This may be found by the well known formula which expresses the equivalence of energy and mass, $E = mc^2$.
1 amu $= 1.66 \times 10^{-24}$ gram.

Radioactivity

Curie: that amount of a radioisotope which undergoes 3.7×10^{10} disintegrations per second.

Rutherford (rd.): that quantity of a radioisotope which undergoes 10^6 disintegrations per second. This unit is recommended by the National Bureau of Standards, but the curie is in more widespread use in industry.

Roentgen (r): that quantity of x rays or gamma rays which will produce by ionization one electrostatic unit of charge in 1 cc of dry air at standard temperature and pressure. The roentgen measures total radiation.

Roentgen per hour at one meter (rhm): the radiation intensity unit recommended by NBS. The International Commission on Radiological Units (ICRU) recommends that radiation intensity be defined as the energy crossing unit normal area per unit time, with units of erg/(sq cm) (sec) or watts/sq cm.

Rad: the unit of absorbed dose of any ionizing radiation.
1 rad $=$ 100 ergs per gram.

Cross Section

Barn: microscopic cross sections are defined so that their dimensions are the same as for an area.
1 barn $= 10^{-24}$ sq cm.

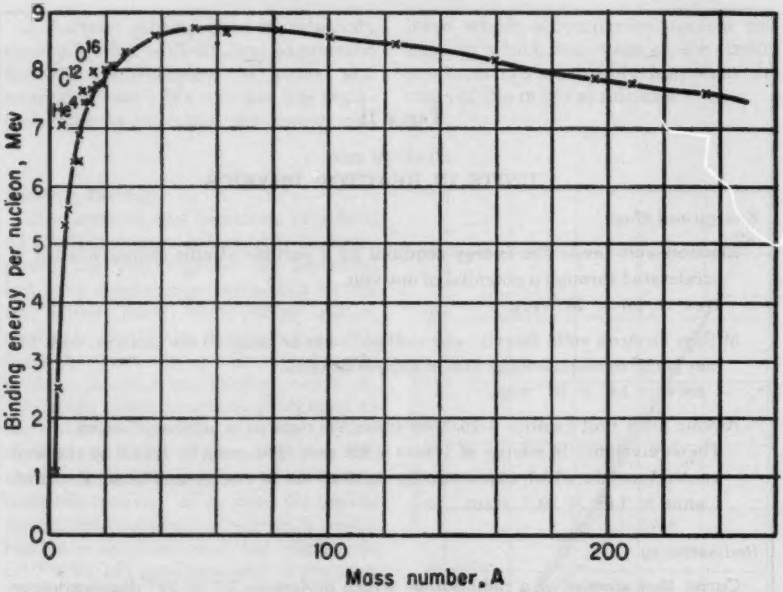


Figure 4. Binding energy per nucleon for stable nuclides. (Reprinted with permission from *Introduction to Nuclear Engineering* by R. Stephenson, 1954, McGraw-Hill Book Co., Inc.)

It may be seen from Figure 4 that the binding energy per nucleon for stable nuclides is low for the lightest elements, reaches a maximum of about 8.7 mev for mass numbers near 60, and then decreases gradually with greater mass numbers.

Fission and Fusion

Contemplation of the variation of binding energy per nucleon from one nuclide to another provides an explanation for the large amounts of energy available in nuclear reactions. Suppose, for example, that we could induce a heavy atom such as U^{235} to split into two lighter atoms. As will be discussed later, the most probable products of such a fission will be an atom of mass near 95 and one near 140. The binding energy per nucleon for U^{235} is 7.6 mev, while those for mass number 95 and 140 are about 8.6 and 8.3 mev, respectively. Ignoring at this time the fact that free neutrons are also produced, we may calculate the energy release per fission to be the difference of binding energies:

U^{235} binding energy $= 7.6 \times 235 = 1{,}786$ mev
Fission product binding energy $= 8.6 \times 95 + 8.3 \times 140 = 1{,}979$ mev

Hence, nearly 200 mev per fission would be released in such a process. The nature and distribution of this energy will be discussed in more detail later.

Great energy release is also possible if we can cause light nuclei to combine to form nuclei with greater binding energy per nucleon. Deuterium has a binding energy of 1.11 mev/nucleon,

while helium has a binding energy of 7.05 mev/nucleon. The energy release accompanying the synthesis of He^4 from two H^2 atoms would be calculated as follows:

Binding energy of 2 H^2 atoms: $2 \times 2 \times 1.11 = 4.44$ mev
Binding energy of He^4 atom: $4 \times 7.05 = 28.20$ mev

The energy release predicted per He^4 atom synthesized would therefore be nearly 24 mev. It is clear then that at least from a mass-energy standpoint, nuclear reactions will be possible whose reactants are away from the maximum binding energy region of Figure 4 and whose products are closer to this maximum. The reactions are referred to by the terms *fission* or *fusion* according to which side of the maximum the original nuclei lie.

Nuclear Reactions

Transmutation of the elements had become fairly commonplace in the world of physics long before the first chain-reacting pile became a reality. Rutherford in 1919 bombarded nitrogen nuclei with alpha particles to produce an isotope of oxygen and a proton:

$$_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1H^1$$

This reaction may be written more briefly as N^{14} (α,p) O^{17}. Incidentally, O^{17} also occurs naturally and is a stable element. Although Rutherford used alpha-particles from naturally radioactive uranium, modern investigators are able, by means of particle accelerators, to transmute elements with much more ease because of the very high velocities which can be imparted to charged particles such as protons and alphas. Unfortunately, however, the coulomb repulsion forces which exist between these positively charged "projectiles" and all nuclei make them less than ideal for most purposes. Much more effective in bringing about nuclear reactions is the neutron, which may be obtained by bombarding beryllium with alpha particles:

$$_4Be^9 + {}_2He^4 \rightarrow {}_0n^1 + {}_6C^{12}$$

This is the reaction by which neutrons were first produced and recognized.

A much more important source of neutrons for experimental purposes nowadays is the research or testing reactor. Neutrons of many different energies are produced in astronomical numbers in a sustained chain reaction, and "windows" are provided in the core so that some of these neutrons may be made available for inducing reactions in test specimens.

Cross Section

Because of the enormous number of atoms present in a macroscopic sample of any element, it is evident that in considering nuclear reactions we are not usually concerned with the fate of any one particular nucleus but rather with the net effect upon the entire group. Furthermore, since the projectiles which we may use—of which neutrons are the most important—are as small as or smaller than the nucleus, and since the nucleus itself occupies only a very small fraction of the volume of each atom, the process of bringing about nuclear reactions is one of firing many projectiles at random in the general direction of many targets.

The probability that a particular reaction will take place is called the *cross section* of the material for that reaction with a particular incident particle. If a uniform beam of intensity I_0 particles/(sq cm) (sec), all travelling in the same direction, impinges on a target of thickness x, the beam will be attenuated when some of the particles react with the target nuclei and the particle intensity will decrease with x (Figure 5). The probability or cross section (σ) for the reaction is

just the rate at which the reactions are taking place divided by the product of particle intensity times target atoms per sq cm, $I\,\overline{N}\,dx$, which represents a measure of the chance for an interaction. $\overline{N}$ is the number of atoms per cu cm of target. But the rate at which reactions are taking place is measured directly (but negatively) by the number of particles being removed from the beam, one less particle being present after each interaction. Hence the probability may be written

$$\sigma = \frac{(-dI)}{I\,\overline{N}\,dx}$$

This integrates readily to

$$I = I_0 e^{-\sigma \overline{N} x}$$

The quantity σ refers to the probability that a particular nucleus will react and is called the *microscopic cross section*. The quantity $\overline{N}\,\sigma$ represents the cross section of all nuclei in 1 cu cm of target material and is called the *macroscopic cross section* (Σ). For an element,

$$\Sigma = \sigma\,\rho\,N/M$$

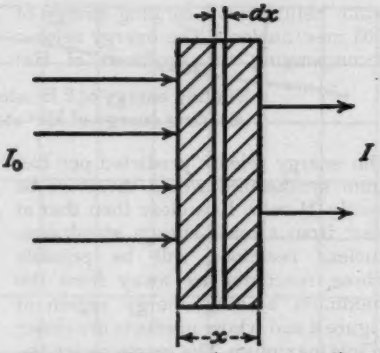


Figure 5. Diagram for cross sections. (Reprinted with permission from *Introduction to Nuclear Engineering* by R. Stephenson, 1954, McGraw-Hill Book Co., Inc.)

The units of σ are sq cm or *barns*, the latter unit being 10^{-24} sq cm.

It can be shown that the average distance, λ, which a particle travels in the target material before reacting is equal to the reciprocal of the macroscopic cross section. This quantity is called the *mean free path*.

RADIOACTIVE DECAY

Modes of Decay

Nuclei which lie outside the stable range of neutron to proton ratio shown in Figure 3, as well as some nuclides which are unstable even though they are within this range, will decay with various half-lives and in various manners. The most important of these modes of decay and the general circumstances under which they occur are as follows:

a. *Alpha emission.* Most of the heavy elements decay in this manner, frequently with accompanying gamma emission. U^{238}, for example, decays with a half-life of 4.5×10^8 years

$$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$$

b. *Beta emission.* A negative electron is ejected from the nucleus with the effect that the atomic number is increased by one. The next step in the U^{238} chain, for example, is

$$_{90}Th^{234} \rightarrow {}_{91}Pa^{234} + \beta^{-}$$

Beta emission is particularly common in reactor fission nuclei, which have an abnormally high neutron to proton ratio. With beta emission, however, it is found that the particles do not have one energy, but that a distribution of energies is obtained as shown in Figure 6 for P^{32}. The product nucleus, S^{32}, has a smaller mass than P^{32} by an amount which just corresponds to the 1.69 mev upper limit of beta kinetic energy. The emission of a beta particle of less than the maximum energy is thought to be accompanied by a *neutrino* which takes the remaining energy. Other beta

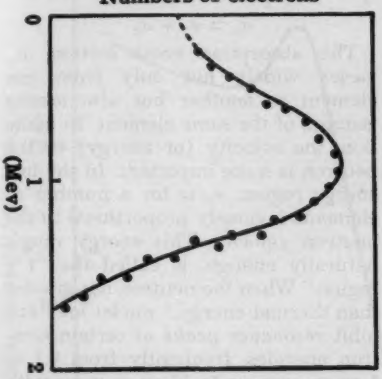


Figure 6. Experimental distribution curve for the electrons from P^{32}. The upper limit of 1.69 mev corresponds to the difference in mass between P^{32} and stable S^{32}. (Reprinted with permission from *Applied Nuclear Physics, 2nd Ed.*, by E. C. Pollard and W. L. Davidson, 1951, John Wiley and Sons, Inc.)

emitters have distribution curves similar to Figure 6.

c. *Gamma emission.* A gamma photon may be emitted whenever the nucleus is in an excited state. Just as there are various energy levels for orbital electrons above the stationary states, so there are various nuclear energy levels above the ground state. Since the binding energy of a nucleon (around 8 mev) is so much greater than that of an orbital electron (of the order of 0.01 mev), it is reasonable that the gamma photons should carry much more energy than the x-rays previously discussed, although both are electromagnetic radiation (see Figure 2).

d. *Positron emission.* A positively charged beta particle may be emitted from a nucleus with an excessively high proton to neutron ratio provided there is a sufficient energy difference (at least 1.02 mev) to permit creation of the positron. Annihilation radiation of two 0.51 mev gamma rays always follows positron emission:

$$_{+1}e^{0} + {}_{-1}e^{0} \rightarrow 2\gamma \quad (0.51 \text{ mev each})$$

e. *Electron capture from the K-shell.* A nuclide with excessive protons may capture a K-electron if insufficient energy is available for positron emission. Capture is followed by emission of a characteristic x-ray.

f. *Internal conversion.* Nuclear excitation energy may be transferred to a K-electron, with emission of the electron and a characteristic x-ray.

g. *Neutron emission.* This decay process is very rare because of the approximately 8 mev binding energy which must be supplied. The shielding and maintenance problems of reactor coolant piping and machinery (outside the core) would be greatly multiplied if fission products were neutron emitters.

Decay Law

It is known that the rate of decay of a radioactive isotope is proportional to the amount of the isotope present, i.e.,

$$\frac{dN}{dt} = -\lambda N$$

where N is the total number of atoms and λ is the *decay constant.* The negative sign is necessary since N is decreasing with time (t).

This differential equation is readily integrated to give

$$N = N_0 e^{-\lambda t}$$

where N_0 is the number of atoms present at time zero. It is easy to show that the time required for half of a sample of N_0 atoms to decay, i.e., when $N = N_0/2$, is $0.693/\lambda$. This quantity is called the *half-life* of the nuclide.

Because of the convenience of measuring the *activity,* A, of a radioactive sample, it is convenient to rearrange the above equations somewhat. The activity is the rate of decay, $\frac{dN}{dt}$, which is measured by a Geiger counter or other such instrument. It can be shown readily that

$$A = A_0 e^{-\lambda t}$$

THE NEUTRON

Properties

The neutron decays with a half-life of 20 to 30 minutes according to the reaction

$$_0n^1 \rightarrow {}_1H^1 + {}_{-1}e^0 + \text{neutrino}$$

It is this reaction within the nucleus which is believed to take place in beta decay. Although 30 minutes is a short half-life, the decay of free neutrons according to the above equation is not common because neutrons are captured so readily by nuclei that their average life is shorter even than their (radioactive) half-life.

The detection of neutrons is not direct as is that of the positively charged particles which interact with electrons and, therefore, readily produce measurable amounts of ionization. Neutrons are indirectly detected by conventional ionization instruments, however, either by the introduction into the counter of a material with which the neutrons will interact; or else by detecting the recoil of light nuclei which are highly ionizing after being struck by neutrons.

Neutron Cross Sections

A neutron may interact with a nucleus in different ways, and the idea of the cross section is used to describe the probabilities of these different interactions. The *scattering cross section*, σ_s, is the probability that a neutron will strike a target nucleus and will rebound in an elastic manner, i.e., momentum and energy conservation laws are satisfied and the nucleus and the neutron are unchanged except in their velocities. The *absorption cross section*, σ_a, is the probability that the neutron will be taken into a target nucleus. The *total cross section* is then

$$\sigma_t = \sigma_s + \sigma_a$$

For nuclei which may fission, it is possible to define *fission cross section*, σ_f, and *non-fission capture cross section*, σ_c, analogously, such that

$$\sigma_a = \sigma_f + \sigma_c$$

The absorption cross section, σ_a, varies widely not only from one element to another but also among isotopes of the same element. In addition, the velocity (or energy) of the neutron is quite important. In the low energy region, σ_a is for a number of elements inversely proportional to the neutron velocity. This energy range, naturally enough, is called the "1/v region." When the neutron has greater than thermal energy,* nuclei may exhibit *resonance peaks* at certain neutron energies, frequently from 0.1 to 1 ev or even up to 10 ev or more with heavy nuclei. For fast neutrons, in the mev range, the cross sections are again small, even for materials which are very strong absorbers at lower energies. Figure 7 shows graphs of σ_t for cadmium, which exhibits the behavior just described with a resonance peak at 0.176 ev.

Slowing Down

Although reactors have been built utilizing fast and intermediate-speed neutrons to sustain fission, thermal neutron fission is the most important at the present time. However, the energy spectrum for fission neutrons covers a wide range, with most neutrons having 1 or 2 mev energies. Before many of these neutrons can themselves cause fission, therefore, their energies must be reduced.

The material which is used to absorb the kinetic energy of the neutrons during the thermalizing process is called the *moderator*. It should not absorb neutrons (we do not purchase a wolf to guard the lambs); should have a large cross section for scatter (Σ_s);

*Neutrons that have lost kinetic energy until they are as likely to gain energy from collisions with the nuclei of their environment as they are to lose energy are called *thermal neutrons*. This energy is about 1/40 ev at ordinary temperatures and corresponds to a neutron velocity of about 2200 m/sec.

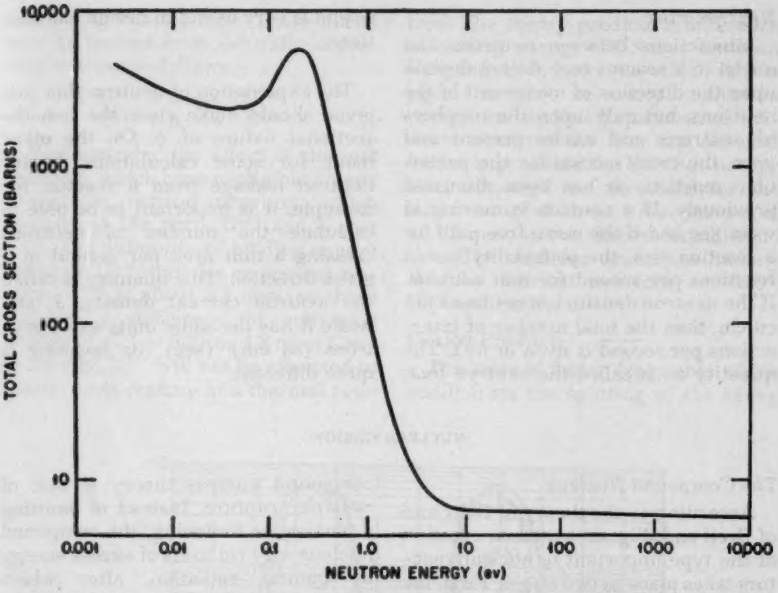


Figure 7. Absorption of neutrons by cadmium, showing the resonance peak at 0.176 ev. (Reprinted with permission from *Sourcebook of Atomic Energy* by S. Glasstone, 1950, D. Van Nostrand Co.)

and should absorb as much energy per collision as possible. For *elastic scattering,* usually compared to the collisions between pairs of billiard balls, it is not difficult to show that the greatest average energy transfer per collision occurs when a neutron strikes a nucleus of equal mass, i.e., a hydrogen nucleus, and that the average number of elastic collisions required to thermalize a 2 mev neutron, for example, increases from 18 for H^1 to 25 for H^2, 114 for C^{12}, and so on up to 2,172 for U^{238}.

The *slowing down power* of a material is defined to be inversely proportional to the number of collisions for thermalization and directly proportional to the macroscopic scattering cross section, Σ_s, since there is obviously little advantage to a small necessary number of collisions if the collisions are extremely unlikely to occur (small Σ_s).

On this basis, the slowing down power becomes a direct measure of the ability of a material to slow down neutrons, but it does not reflect the tendency for absorption during the slowing-down process. Consequently, another quantity, the *moderating ratio,* is defined as the slowing down power divided by the macroscopic absorption cross section. Values of the moderating ratio for a few substances are as follows: water, 72; heavy water, 12,000; carbon, 170. The moderating ratio is a true indication of the effectiveness of a material as a moderator.

Neutron Flux

Interactions between neutrons and nuclei in a reactor core do not depend upon the direction of movement of the neutrons, but only upon the numbers of neutrons and nuclei present and upon the cross section for the particular reaction, as has been discussed previously. If a neutron is moving at v cm/sec and if the mean free path for a reaction is λ, the probability is v/λ reactions per second for that neutron. If the *neutron density* is n neutrons per cu cm, then the total number of interactions per second is nv/λ or $nv\Sigma$. The quantity nv is called the *neutron flux*, ϕ, and is very useful in design calculations.

The explanation of neutron flux just given should make clear the non-directional nature of ϕ. On the other hand, for some calculations, as for neutron leakage from a reactor, for example, it is important to be able to calculate the number of neutrons crossing a unit area per second in a given direction. This quantity is called the *neutron current density*, J, and while it has the same units as ϕ, neutrons/(sq cm) (sec), its meaning is quite different.

NUCLEAR FISSION

The Compound Nucleus

According to the theory of Bohr and of Breit and Wigner, a nuclear reaction of the type important to nuclear reactors takes place in two stages. First, the incident particle is absorbed by and becomes a part of the target nucleus; then, if energy and stability limitations permit, the compound nucleus disintegrates to form a new nucleus and an ejected particle. Because particle emission does not occur until after the incident particle has become part of the excited compound nucleus, the mode of decay of the latter is independent of its mode of formation.

An important reaction which may be considered in the light of the compound nucleus model is that of fission of U^{235} by a slow neutron. The two steps may be written as follows

$$U^{235} + {}_0n^1 \rightarrow U^{236}$$

$$U^{236} \rightarrow {}_{z_1}F_1^{A_1} + {}_{z_2}F_2A_2 + \nu_0n^1$$

The second equation indicates two fission fragments of unspecified identity and ν neutrons. These quantities will be discussed in more detail later.

Another important reaction which can be interpreted by means of the compound nucleus theory is that of *radiative capture*. Instead of emitting a particle or fissioning, the compound nucleus may rid itself of excess energy by gamma radiation, after which particle emission may no longer be energetically possible.

Critical Energy

Consideration of the binding energy curve of Figure 4 would lead to the conclusion that it is energetically possible for any element of mass number greater than about 100 to fission spontaneously, since the binding energy per nucleon of such a nucleus would be less than that of its fission fragments. The fact that this does not occur for most such elements is explained by the necessity for nuclei to be supplied with a certain *critical* or *activation energy* before fission can take place. The magnitude of this energy varies from one nuclide to another and is a measure of the stability of each nucleus.

According to calculations which will not be given here, the activation energy for the compound nucleus U^{236} is 6.8 mev, while that for the compound

nucleus U^{239} is 7.1 mev. These nuclei may be formed from naturally occurring isotopes as follows

$$U^{235} + n \rightarrow U^{236}$$
$$U^{238} + n \rightarrow U^{239}$$

Now consider the effect of thermal neutrons, which have negligible kinetic energy, in natural uranium, which consists of 139 parts U^{238} and 1 part U^{235}. The difference of binding energy between U^{238} and the compound nucleus U^{239} is about 5.3 mev, so there will be a deficiency of activation energy of (7.1 − 5.3) or 1.8 mev. Consequently, U^{238} will not be expected to fission upon capture of a thermal neutron. The theory predicts a difference of binding energy of 6.8 mev between U^{235} and U^{236}, however, which is just equal to the necessary activation energy for fission. Experimental evidence confirms the fact that thermal fission is probable for U^{235} but not for U^{238}, although the threshold for the latter occurs at about 1 mev instead of at 1.8 mev as the theory would indicate. The nuclides which are fissionable by thermal neutrons are U^{235}, U^{233} and Pu^{239}.

Fission Products

The pairs of fission fragments which result from the splitting of the heavy

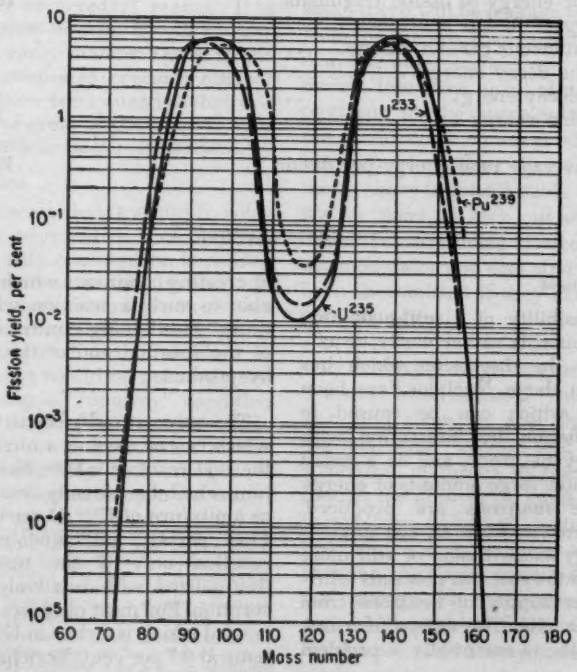


Figure 8. Fission product yields for U^{235}, Pu^{239} and U^{233}. (Reprinted with permission from *Introduction to Nuclear Engineering* by R. Stephenson, 1954, McGraw-Hill Book Co., Inc.)

nuclei which are used as nuclear fuels (U^{235}, U^{233} and Pu^{239}) are almost never identical. Figure 8 shows the experimentally determined yields for these nuclides with thermal neutrons, and from these it can be seen that the fragments usually consist of one mass number near 95 and one near 139. Each of these occurs with a frequency of 6 or 7 per cent, while equal mass numbers occur with frequencies of no more than a few hundredths of one per cent. More than 60 different elements have been identified from thermal neutron fission of U^{235}, for example, with mass numbers varying from 72 to 158.

It is found that, on the average, there are about 2.5 *prompt neutrons** emitted per thermal neutron fission of U^{235}. In addition, considerable gamma-radiation accompanies fission. In spite of the prompt neutrons which are emitted, however, the fission fragments are left with a neutron to proton ratio which is too great for stability (Figure 3). Occasionally the adjustment is made by neutron emission, giving rise to delayed neutrons, but more often beta decay takes place. Considerable energy is also released in gamma radiation of the decay products. The approximate distribution of fission energy is as follows:

Kinetic energy of fission fragments	162 mev
Energy of fission neutrons	6
Instantaneous gamma energy	6
Gamma decay energy	5
Beta decay energy	5
Neutrino energy	11
Average total energy per fission	195 mev

THE CHAIN REACTION

Nuclear Fuels

The possibility of a self-sustaining chain reaction is rather easily visualized from the discussion which has been given above. Nuclides have been described which can be caused to undergo fission by interaction with low-energy neutrons, and as a result of this fission, large amounts of energy and more neutrons are produced. These neutrons, when slowed to thermal energy cause fission of still more nuclei, and the reaction proceeds without further supply of neutrons from outside the pile. The design of a nuclear reactor is essentially a problem of creating conditions which are favorable to such a reaction while, at all times, maintaining control of the rate of the reaction and of the dangerous by-products.

The only naturally occurring isotope which can be used as a nuclear fuel in thermal reactors is U^{235}. Natural uranium, which has already been described as a mixture of U^{235} (1 part) and U^{238} (139 parts), will sustain a chain reaction only if the neutrons are thermalized with relatively little absorption. For most purposes, a mixture is used which is richer in U^{235} than the natural 0.7 per cent. Enrichment in the amount of a few per cent has been reported in the unclassified literature for water cooled and moderated power reactors.

*Prompt neutrons are those which are produced at the time of the fission of the compound nucleus into the two fission fragments. Neutrons which are emitted by the fission fragments are called *delayed neutrons*.

Because of the inherent difficulties of seperating the two isotopes of uranium, considerable effort has been expended on the production of plutonium (Pu^{239}) as a nuclear fuel. The huge production reactors at the Hanford Works of the A. E. C. (now operated by the General Electric Company) were built to convert U^{238} to Pu^{239} according to the reaction

$$_{92}U^{238} + {}_{0}n^{1} \rightarrow {}_{92}U^{239} \rightarrow {}_{94}Pu^{239} + 2\,{}_{-1}e^{0}$$

These reactors utilize natural uranium to maintain the chain reaction, with graphite moderator to slow the neutrons and with circulating water to remove the unwanted energy liberated by the chain reaction. Pu^{239} behaves about like U^{235} as a reactor fuel, according to data released by the A.E.C.

The third isotope which is important as a fuel is U^{233}, which is produced from the metal thorium by the following reaction:

$$_{90}Th^{232} + {}_{0}n^{1} \rightarrow {}_{90}Th^{233} \rightarrow {}_{92}U^{233} + 2\,{}_{-1}e^{0}$$

This reaction can be brought about in a *converter* or *breeder** reactor. It is not yet known how far it will be economical to carry the conversion of the common isotopes to precious nuclear fuel, but there is no question that this process is of great importance to economical nuclear power production.

Critical Mass

It would seem that it would be relatively easy to maintain a chain reaction when only one neutron is needed for each nucleus which fissions, and when each such fission produces two or three neutrons. In fact, these figures would indicate that the problem of reactor design would be primarily one of preventing a "runaway" condition similar to that of an atomic bomb. However, other factors enter to decrease considerably this margin of (2.5-1) or 1.5 neutrons per fission.

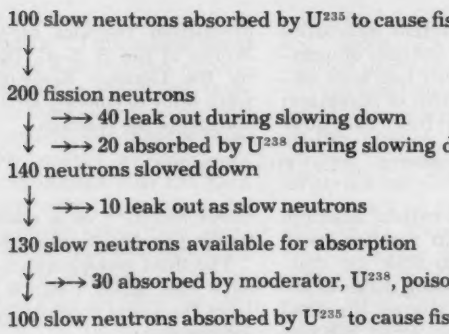
Since the reactor core is of finite size,† there will be leakage of neutrons from the surface. Fuel nuclei which are near the outer surface will, when they fission, lose some or all of their fission neutrons to the surroundings. Since the neutrons which are produced have high kinetic energy (usually 1 or 2 mev), there is considerable opportunity for them to leak out of the core while they are being slowed down by the moderator and also after they have been thermalized if they are near the core boundary.

A relatively large number of neutrons are absorbed in U^{238} without fission, and some are also absorbed by the moderator, coolant and necessary structural materials in the core. Although the absorption cross section Σ_a is small for nearly all materials with fast neutrons, it becomes very great at many resonance peaks and at thermal energy for many common materials. Glasstone and Edlund‡ give an illustration of a neutron balance which might exist in a system where a chain reaction is taking place at a constant rate:

*The generally accepted distinction between a converter and a breeder is that, in the latter, more fuel material (say U^{233}) is produced than is used to maintain the reaction. A converter, on the other hand, is designed to change some U^{238} or Th^{232} to fuel, but at a slower rate than fuel is being used in the chain reaction.

†Most power reactors being considered at the present time have cores of the order of size of a right circular cylinder 5 or 6 ft. in diameter and about the same height.

‡Glasstone, S. and M. C. Edlund, "The Elements of Nuclear Reactor Theory," Van Nostrand (1952).


100 slow neutrons absorbed by U235 to cause fission
200 fission neutrons
40 leak out during slowing down
20 absorbed by U238 during slowing down
140 neutrons slowed down
10 leak out as slow neutrons
130 slow neutrons available for absorption
30 absorbed by moderator, U238, poisons, etc.
100 slow neutrons absorbed by U235 to cause fission

Since the number of neutrons which produce fission is constant, the reaction continues at a constant rate.

Since the volume of a reactor core, and therefore the mass of fuel, increases as the cube of the radius (or other characteristic linear dimension), while the surface area increases only with the square of the radius, it follows that neutron leakage can be made relatively less important by increasing the size (hence, the mass) of the core. The minimum amount of material which will sustain a chain reaction for a given composition, geometry, etc., is called the *critical mass.*

Multiplication Factor

Consider a reactor of indefinitely large size, for which neutron leakage and other surface effects may be neglected, and express the condition of criticality in terms of a *multiplication factor,* k, which is defined as the ratio of the number of neutrons of any one generation to the number for the preceding generation. When $k=1$, the chain reaction will proceed at a constant rate (fissions per unit time) and power generation will be constant.

In order to bring a reactor up to power, it is necessary that it be possible for k to be greater than unity, and in order to decrease the power, k must be decreased to less than one. If the number of neutrons present at any time t be represented by n, it follows that the rate of increase of neutrons per generation will be $n(k-1)$, and if the average time between generations is l seconds, then the rate of change of neutrons is

$$\frac{dn}{dt}=\frac{n(k-1)}{l}$$

or $n=n_0e^{(k-1)t/l}$

where $n=n_0$ when $t=0$. Hence the increase or decrease in neutron population, and therefore in power level, is exponential with time.

The number of fast neutrons produced per slow neutron which causes fission, ν, has previously been given as 2.5 ± 0.1, on the average. Since not all slow neutrons which are absorbed by the fuel do cause fission, it is necessary to multiply ν by a ratio of cross sections to obtain the number of fast neutrons produced per slow neutron absorbed in the fuel (with or without fission). If the latter number is denoted by η,

$$\eta=\nu\frac{\Sigma_f}{\Sigma_a}$$

where Σ_f and Σ_a are the macroscopic cross sections of the fuel for fission and total absorption (fission plus nonfission capture), respectively. Conse-

quently, we now have ηn fast neutrons emitted from the n thermal neutrons captured.

As described previously, the probability of fast neutron fission of the heavy elements such as U^{235} and U^{238} is fairly small, insufficient to sustain a fast fission chain reaction in natural uranium, for example. Nevertheless, the fast neutrons in a thermal reactor do cause fission of some of the U^{235} and U^{238} (or other fuel) before they are slowed down, and an allowance is made for this in the *fast fission factor*, ε. This quantity is defined as the ratio of the number of all fast neutrons produced to the number produced by thermal neutrons and has a value of about 1.03 with graphite or heavy water moderator. Hence, the total number of fast neutrons produced is $n\eta\varepsilon$.

Many of the neutrons will be captured without fission during the slowing down process. The fraction which reaches thermal energy without loss is denoted by p, the *resonance escape probability*, and the number of thermal neutrons produced becomes $n\eta\varepsilon p$.

Finally, it is observed that not all the neutrons which survive long enough to become thermalized are absorbed by the fuel. Some may be absorbed by the other materials present in the core, so that a quantity called the *thermal utilization factor*, f, is defined as the fraction of thermal neutrons which are absorbed by the fuel. The values of p and f depend upon the reactor design, especially on the materials used, and it is up to the designer to keep these fractions as near to unity as possible.

If the quantities just defined are combined, it is seen that the number of thermal neutrons which cause fission in the new generation, $n\eta\varepsilon pf$, divided by the number in the previous generation, n, is just the multiplication factor which was previously defined

$$k = \eta\varepsilon pf$$

This formula, the *four factor formula*, expresses algebraically the criterion that k must be unity for a chain reaction to continue at a constant rate. Since it refers to an infinite system, this value of k is usually called k_∞, the *infinite multiplication factor*.

When there is neutron leakage from the reactor core, as there will always be with a reactor of finite size, k must be greater than unity if a reaction is to be continued. The probability that a neutron will remain in the pile throughout its lifetime is called the *nonleakage probability*, P, and the condition for a chain reaction to be maintained is that $kP=1$. The product kP is called the *effective multiplication factor*, k_{eff}.

Reactor Control

To operate a reactor, it is necessary that means be provided to change the effective multiplication factor to slightly more than unity to bring up the power level; to decrease k_{eff} to unity for steady operation; and to decrease k_{eff} below unity for power decrease and shutdown. The common way to accomplish these changes is by means of control rods which may be positioned in such a way that they will absorb enough neutrons to give the desired effect. These rods contain a strong neutron absorber such as boron or cadmium.

When the control rods are inserted, they absorb neutrons in such numbers that k_{eff} is less than one, and the reactor is said to be *subcritical*. As one or more rods are gradually withdrawn, k_{eff} approaches, then equals, and finally exceeds unity. The reactor is then said to be *supercritical* and the power level quickly rises. When the desired power level is reached, the rods

are partially inserted until $k_{eff}=1$, and the reactor is *critical* but is at steady state condition.

A characteristic of the fission reaction of great importance to reactor control is the production of delayed neutrons. For U^{235}, for example, about 0.75 per cent of the fission neutrons which are produced are not emitted with the fission fragments immediately upon fission, but are emitted by the fission fragments after a time delay. Whereas the prompt neutrons which represent more than 99 per cent of the total are emitted after about 10^{-14} sec, many of the delayed neutrons are produced at intervals of one-half sec to 1 minute or more after fission. If k_{eff} is between one and 1.0075, the effect of the delayed neutrons is to make the effective neutron life fairly long (0.1 sec) and the rate of increase of neutron population, and consequently of power level, is fairly gradual and easy to control.

When k_{eff} is equal to 1.0075, the reactor is said to be *prompt critical*. When this value is exceeded, multiplication occurs from prompt neutrons alone, and the control is very difficult because of the extremely rapid rate of increase of the fission rate.

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POWDER METALLURGY—

ITS ROLE IN THE DESIGN OF NUCLEAR-POWER REACTORS

ACKNOWLEDGEMENT

This paper, presented at the American Society of Mechanical Engineers' Diamond Jubilee Spring Meeting in Baltimore, April 18-21, 1955, was published in the August, 1955, edition of *Mechanical Engineering*. The authors are H. H. Hausner and M. C. Kells of the Atomic Energy Division of Sylvania Electric Products, Inc.

There are many material problems involved in the design of nuclear-power reactors (1).* For example, take a nuclear reactor using graphite as the moderator. The graphite blocks are pierced by a symmetrical array of aluminum tubes which act as coolant pipes. The uranium metal-fuel slugs in suitable containers are loaded into the aluminum tubes. Boron-steel control rods penetrate the core and regulate the neutron density. The core is surrounded by the concrete reflector and biological shield. Holes penetrating the core make possible the production of radioisotopes.

A gas-cooled reactor proposed by the Commonwealth Edison Company of Chicago will contain uranium fuel elements with an internal temperature somewhere between 1000 and 1300 F. Helium is proposed as the coolant with an inlet temperature near 450 F and an outlet temperature in the range of 700 to 750 F, assuming a gas flow of approximately 3.27×10^6 lb per hr (2).

Another reactor proposed by Dow-Detroit Edison Company is designed for a liquid-metal coolant such as sodium. The coolant temperature could be somewhere between 800 and 1100 F. A similar, but not identical, reactor has been proposed by the Monsanto Chemical Group.

The reactor designed by the Pacific Gas and Electric Company uses water as a coolant. All the reactor elements, the fuel, coolant, coolant transportation system, the moderator, any internal structural materials, and the reactor-control elements, will necessarily operate at elevated temperatures.

The metallurgical problems in the design of reactors are, therefore, characterized by the behavior of metals, and the reactions between metals, at elevated temperatures and under irradiation (3). These problems include:

* Numbers in parenthesis refer to the Bibliography at the end of the paper.

(a) mechanical behavior at elevated temperatures; *(b)* corrosion behavior; *(c)* thermal conduction; *(d)* heat transfer; *(e)* radiation damage.

There are, of course, many more metallurgical problems concerned with the neutron-absorption cross sections of the reactor materials and the formation of radioactive isotopes in the removable components.

The mechanical-metallurgical problems concern practically all the metal components in the reactor, those for structural purposes as well as operating parts, including the fuel metal, the coolant, and others.

Fuel Metal. The basic difference between the fuel metal and other common metal parts at elevated temperatures can best be described by the difference in the direction of heat flow. Common metals during heating usually receive the heat from the outside, whereas the fuel metals produce the heat internally from fission. Whereas common metals can be heated from the outside to a perfectly uniform temperature throughout, the fuel metal producing the heat under irradiation will always have a higher temperature inside than outside. The temperature gradient between the center of the fuel element and the surface is a function of many variables, the most important ones being: neutron flux; shape and physical dimensions of the element; type and circulation speed of the coolant; thermal conductivity of the fuel material.

Any mechanical calculations concerning fuel elements have to take this temperature gradient and, therefore, the stresses caused by this gradient, into consideration. These stresses make predictions of the behavior of the elements difficult since creep of the fuel metal is affected.

In addition, these stresses are of prime importance in all problems concerning the bond between a fuel-element metal and the protective fuel-element cladding. Any high-temperature reactor utilizing metallic fuel elements requires a reliable bond between fuel metals and cladding, especially for heat-conduction reasons. The cladding metal has to be chosen carefully; it must have a low neutron-absorption cross section for reasons of neutron economy, its thermal expansion must match that of the fuel metal to a certain extent, and it must resist corrosion under the operating conditions. Inasmuch as the fuel elements operate at elevated temperature, care must be taken to avoid diffusion of the fuel metal into and through the cladding during operation.

Complicated mechanical problems will be encountered when the coolant is a liquid metal; however, these problems are not pertinent to the powder-metallurgical aspects with which this paper is concerned.

Corrosion. Most of the corrosion problems in a nuclear-power reactor are related to the type, temperature, and pressure of the coolant. There is a general agreement among reactor designers that the fuel material should be placed in a sealed container in order to prevent corrosion and erosion by the coolant. However, even when the nature of the coolant does not promote corrosion, as is true in the case of argon, it will be necessary to clad the fuel material in order to prevent radioactive fission fragments from entering the coolant. Some of the metals considered for cladding materials or for coolant pipe lines have been developed only recently, and little is known about their corrosion behavior. Where liquid metals are used as coolants, there is danger that they may react with the cladding material.

Corrosion in a nuclear-power reactor may take place at the following

points: Between fuel cladding and coolant or between fuel metal and the coolant in case of imperfect cladding.

Static corrosion tests are not sufficient for testing the materials under consideration inasmuch as the coolant in the reactor circulates at a fairly high speed and under pressure. Corrosion problems are difficult in cases where welded joints must be used, as corrosion may be enhanced by alloys formed during the welding procedure.

RADIATION EFFECT

Radiation effect is probably one of the most important problems in the reactor design (4, 5, 6, 7). Metallurgists and solid-state physicists are still searching for correct theoretical explanations for the phenomena observed.

During the past few years, it has been shown that the physical properties of many materials change under irradiation; these changes vary with the type, density, and duration of radiation, and also with the type and structure of the material. It is fairly well agreed at present that organic compounds are affected by beta, gamma, and neutron radiation, and that the disturbances in these materials can be explained by ionization. Metals, however, being good electrical conductors, seem to be affected chiefly by neutrons. Some of the experimentally observed disturbances in metals can be explained and correlated on the basis of a lattice-vacancy picture, which considers displacements of atoms from their normal crystal lattice positions. It is understandable that the kinetic energy of a fast neutron is high enough to displace atoms during an elastic collision and thus to disrupt the material. As a result of such collisions, we may expect the creation of a number of lattice vacancies, and the removed atoms also may displace still other atoms from the lattice. It is also possible that these displaced atoms excite lattice vibrations of a mean energy corresponding to a temperature higher than the average temperature of the material (5).

It is interesting to note that most of the changes in the physical properties of metals that occur on exposure to neutron radiation resemble the changes occurring as a result of cold-working, although the mechanisms of these two types of change are of an entirely different nature. It also appears that a correlation exists between the degree of cold-working, the heat-treatment of a metal, and the extent of changes under neutron radiation (7).

Fig. 1 shows the effects of irradiation on the tensile strength and yield strength of several metals. From this figure, one can see that especially the yield strength of some metals increases considerably under irradiation and that the increase for nickel is especially high, whereas the increase in yield strength for zirconium is considerably less.

Fig. 2 shows the effects of irradiation on the hardness of the same metals. Radiation increases the hardness very little in hardened metals but considerably more in annealed metals (7). It seems that the lattice dislocations and defects produced by hardening lower the effect of radiation substantially, especially when compared with the radiation effects on annealed metals which are characterized by more undisturbed or at least by less-distorted lattices.

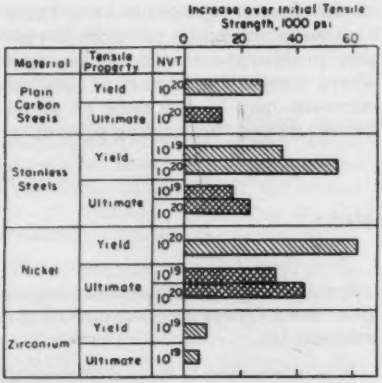

Figure 1. Effect of irradiation on tensile strength of some metals. (Courtesy Reinhold Publishing Company)

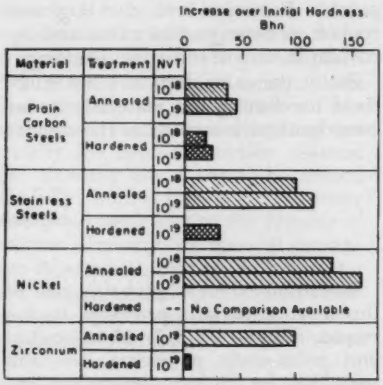

Figure 2. Effect of irradiation on hardness of some metals. (Courtesy Reinhold Publishing Company)

THE ROLE OF POWDER METALLURGY

Metals prepared by powder metallurgy differ in many ways from metals made by conventional methods.

Crystal Lattices in Powder Metallurgy. Metal powders can be fabricated by several mechanical, chemical, or electrochemical methods. According to the method of fabrication, the powder particles differ in shape, size, and structure.

Any powder particle is characterized by the high ratio of its surface area to its mass or volume. This is an important feature with respect to the particle structure, inasmuch as the surface crystal lattices are usually different from the body lattices; they show a large amount of lattice vacancies, dislocations, or other disturbances, so that one may consider these surface lattices as highly disordered. It has been shown before that the radiation effect in a material is closely connected with the degree of disorder in the structure and that a material with higher degree of disorder in the crystal lattices is more resistant to radiation effect than when characterized by ordered lattices.

The lattice distortions in the metal powders progress further during compacting under pressures which vary between 5 and 50 tsi, but which are still much greater in the contact areas where the metal-powder particles touch each other. During the next step in powder metallurgy, i.e., sintering, the lattices rearrange to a certain extent but very seldom end up in ordered structures, although by some heat-treatment after sintering conditions, the lattice structures may change to ordered ones. The disordered lattices resulting from the powder-metallurgical processing may make a material more resistant to radiation effect and this is definitely one advantage powder metallurgy has to offer as a method for fabricating materials for nuclear-power reactors.

Grain Structure in Powder-Metallurgy Products. It must be mentioned that the grain growth in powder-metallurgy products during sintering is different from the normal grain growth in conventionally fabricated metals treated under similar heating

conditions. This matter is of greatest importance and will be discussed in more detail.

The equations governing grain growth in metals are well known. One distinguishes between continuous grain growth and grain growth by cold-work, the more nuclei are formed for recrystallization and, therefore, the smaller the grains are in the structure under development. Grain growth can be hindered by the addition of impurities to the metal. This inhibits grain growth or at least decreases considerably the rate of grain growth. The compact pressed from metal powders contains a large amount of highly cold-worked powder particles. Between the powder particles, there are voids, or holes, which take approximately 10 to 30 per cent of the compact volume. Because of the high degree of cold-work in the powder particles, even before but especially after compacting, a large number of nuclei for recrystallization are formed, which leads, in general, to small grain sizes. Besides, one has to consider further that the voids between powder particles act in a manner similar to impurities; that is, they hinder or delay the grain growth during sintering. This reduction of grain growth during sintering is especially effective during the earlier stages of sintering. As sintering progresses, the voids become smaller and most of them finally disappear. Both facts—the high degree of cold-work in powder particles and the presence of voids—have the effect that powder-metallurgy products are usually characterized by smaller grains in the structure, although the grain sizes can be increased by a heat-treatment above sintering conditions, following the actual sintering operation.

Alloys by Powder Metallurgy. Powder metallurgy offers, also, other advantages with respect to the development of reactor materials. It is well known among nuclear engineers that certain alloys made from fissionable materials with small alloying additions are more favorable with respect to radiation effect and corrosion than the pure fissionable material, although the mechanisms causing these effects are not fully understood as yet. Alloys can be prepared by conventional melting processes in liquid-state reactions or they can be made by powder metallurgy in solid-state reactions. The end product may differ in grain size; however, this may not have any extensive effect on the corrosion resistance of the alloy.

The preparation of certain alloys by powder metallurgy offers some advantages, especially with respect to alloys made from very heavy metals, such as uranium, and very light metals. Ordinary melting of two components with quite a difference in density frequently results in segregation of the two components, and one or even more remelting steps may have to be added in order to obtain a homogenous alloy structure. Remelting, however, like any other long-term, high-temperature process, involves the danger that the metals may pick up definitely undesirable amounts of gaseous impurities. Mixing the two alloying components in the form of powder particles to a high degree of uniformity offers no difficulty, and any subsequent compacting or sintering operation does not disturb the homogeneity of the mixture. Although the large total surface area of the powder particles would usually permit the pickup of gases, powder-metallurgy sintering usually occurs at temperatures far below the melting temperature of the metallic components, and this low-temperature process lowers the possibilities of picking up gaseous impurities. All this indicates that alloys prepared by powder metallurgy may be very useful and offer advantages compared with con-

ventionally prepared alloys in the fabrication of components for nuclear reactors, where impurities play such an important role.

Metallic Compounds and Cermets. It is a well-known fact that certain combinations of metals, which do not form an alloy, can be made by powder-metallurgy methods. These metal combinations are known as compound metals, such as tungsten-copper or molybdenum-silver combinations as used for electrical contacts. In these compound metals, one metallic component is present, either in the form of discrete particles within the matrix of a second component, or in the form of a metallic framework interwoven with another metallic framework.

The materials known as cermets—combinations of metallic and nonmetallic components—are similar to the compound metals and cannot be made by any other method than by powder metallurgy. The development of these cermets is usually directed toward products for high-temperature purposes, such as parts for gas turbines or jet-propulsion engines, and the ceramic components are usually carbides, borides, or other metal compounds bonded together by metals such as nickel, copper, etc. These cermets may offer certain advantages when developed for nuclear-engineering purposes.

The solid-fuel element developed as a cermet could play an important part in any reactor design, and powder-metallurgy fabrication methods are required for these types of materials.

Bonding for Heat-Transfer Purposes. It was stated previously that certain reactor parts ,such as fuel elements, must be clad by another metal in order to prevent corrosion under reactor operating conditions. The "cladding" sometimes has to be well bonded in order to create best conditions for heat transfer which, as pointed out, plays an important role in several reactor components.

A perfect metallurgical or diffusion bond between the metal part to be protected and the protecting metallic cladding, which prevents corrosion, is very desirable in many cases, and powder metallurgy offers some advantages in this respect. Diffusion of one metal into another metal usually requires high temperature or long-term treatment at lower temperatures; both these conditions are not always in the range of possibility for production operations. In order to lower the diffusion temperature or decrease the diffusion time, the metals should have high surface activity, which usually results in an increased diffusion rate. Metal-powder particles, on account of their high curvature and their large number of lattice defects, usually diffuse at lower temperatures, and within a shorter time, than cast metallic bodies. Fig. 3 shows schematically the rate of diffusion.

From this schematic, one can recognize that minimum diffusion occurs between cast metals and that the fastest diffusion rate occurs between metal powders in the unsintered state. Experience has shown that sintered metals diffuse easier than cast metals. This fact makes powder metallurgy interesting with respect to the cladding problems in the development of reactor

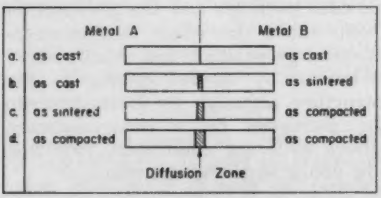

Figure 3. Diffusion between two metals, A and B, under constant temperature, time, and pressure conditions as a function of their method of preparation.

components, inasmuch as conditions can be created which result in perfect heat transfer while minimizing other deletrious effects.

The Powder Metallurgy of Beryllium, Thorium, Uranium, and Zirconium. Beryllium (8), being a very brittle metal, can be prepared in powder form by milling and grinding of the solid material in neutral atmospheres. Uranium (9), thorium (9), and zirconium (10), which are not brittle, cannot be ground so easily; however, they form brittle hydrides when exposed to hydrogen at certain temperatures which are approximately 225 C for uranium (9), 750 C for thorium (9), and 400 C for zirconium (10). Uranium hydride, in itself, is a fine powder, whereas the hydrides of zirconium are solid materials of a high degree of brittleness which can be ground to desirable particle sizes. The decomposition of these hydride powders occurs in vacuo at elevated temperatures and the metal powders formed in this way are applicable to any powder-metallurgical process.

Hazards in Handling Powders. One has to keep in mind, however, that handling of these powders is not so easy as that of copper, iron, or any other ordinary metal powder. Beryllium, in powder form, is highly toxic; zirconium, in fine particle sizes, is highly pyrophoric; and the powders of uranium and thorium are both toxic and pyrophoric. Handling of these powders has to be done, therefore, with greatest care. Dry boxes for manipulating these powders have been well developed by the skill of mechanical engineers and permit safe handling of these dangerous materials.

Compactibility. The compactibility of the four powders is quite different; it depends, to a certain extent, on the particle sizes of the respective powders; to a large extent on the purity; and to the largest extent on the plasticity of the particle material. If generalizations are permitted, we may state that among the four powders, thorium compacts to the highest per cent theoretical density and uranium powder to the lowest density; zirconium and beryllium are just in-between, as shown in Fig. 4.

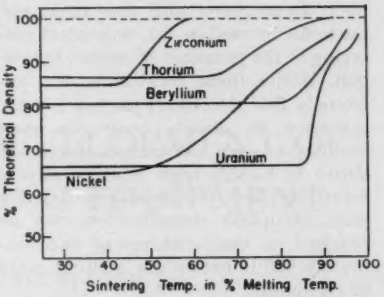

Figure 4. Densification of nickel, zirconium, beryllium, thorium, and uranium powders, compacted at 50 tsi, as a function of sintering temperature.

Sintering. Sintering of the four powders subsequent to compacting is quite different. Zirconium has been found to be an almost ideal material for powder metallurgy, inasmuch as it sinters to high density at temperatures far below its melting point. Thorium also densifies at fairly low temperatures to practically theoretical density, whereas uranium and beryllium start to densify only at fairly high sintering temperatures, approximately 85 per cent of the melting temperatures of these metals. Beryllium and zirconium are most interesting metals from the standpoint of powder-metallurgy sintering.

Zirconium powder, as discussed before, is made by decomposition of zirconium hydride. Zirconium-hydride powder cannot be compacted as well as the zirconium powder but it compacts to such a degree of density that the compact is strong enough to be handled and sintered. During sintering in vacuo, the zirconium-hydride com-

pact decomposes and the zirconium particles formed in this way start sintering in the presence of atomic hydrogen. Under these conditions, the extremely fine zirconium particles in the presence of atomic hydrogen start bonding at very low temperatures and sinter to a very high density, also at relatively low temperatures. In this way, complete densification can be reached at temperatures of approximately 650 C below the melting point of zirconium.

The method of pressing a metal-compound powder, such as a hydride, and ending up with a completely densified, sintered-metal product is quite a novel process and will probably find many further applications. The powder metallurgy of beryllium is also interesting, but from quite a different standpoint. Beryllium must be sintered in a nonoxidizing atmosphere such as argon or vacuum. It densifies fairly uniformly in both of the mentioned sintering atmospheres, but it does not reach full density. There is, however, a big difference between the argon and vacuum-sintered beryllium. Whereas the argon-sintered beryllium is as brittle as described in the literature, the vacuum-sintered beryllium shows some ductility, inasmuch as it can be cold-rolled approximately 10 per cent, annealed, and again cold-rolled. This fact can be explained as follows: During vacuum sintering, evaporation of beryllium starts at fairly low temperatures and acts as an additional sintering mechanism, resulting in grains of certain sizes and shapes which favorably affect the ductility of the material. Evaporation, as a mechanism of sintering, is also a phenomenon which deserves further investigation and study with respect to various metals.

Fig. 4 shows further that all four metals can be densified by cold-pressing and subsequent sintering. The powder-metallurgical method of hot-compacting can also be applied to the four metals and results in complete densification of these materials, similar to any common metal. Needless to say, pressing and sintering or hot-compacting of these toxic and pyrophoric powders has to be done with greatest care in the presence of protective atmospheres such as argon or helium.

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AN OUTLINE OF DEVELOPMENT OF OFFSHORE DRILLING EQUIPMENT

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THE AUTHOR

began his naval career as a Line Officer, and later took a post-graduate course in Naval Architecture in Armstrong College at the University of Durham, England. He was recalled to active duty prior to Pearl Harbor, and retired in 1946 on physical disability with rank of Commander, USNR. At present he is President of the firm of Friede and Goldman, Inc., Naval Architects and Marine Engineers, in New Orleans, Louisiana.

Unless in the future nuclear energy may be widely used in the power plants — fuel oil, whether Bunker "C" or Diesel Oil, shall continue in the years to come to be one of the two major primary sources of generating electric, marine, locomotive, aviation and automotive plant power. The same oil after refining and fractionalization, provides not only the necessary medium for lubrication, but numerous other well-known widely used by-products which become more and more important in daily life. Therefore, even if fuel oil shall be superseded in the future by other prime movers, the demands for it shall not diminish.

Since the Drake Oil Well was first drilled in Pennsylvania until present times, the public visualized the oil fields as a maze of derricks located on the land masses of the earth, which however occupy only one quarter of its surface. However, with increased competition, decrease in available areas for leasing and depletion of oil pools, the oil industry began to move from the dry lands into the shore marshes, and from there it was just a short step to venture into the Gulf of Mexico. When the drilling took place in the marsh land, the problem was relatively simple. The operators built roads over the swamps, provided foundations for the derrick and equipment and proceeded with the drilling. Later it was found advantageous to dredge a slip and to install the drilling derrick and equipment on a slotted barge and tow the barge into the slip. Since the depths of water ranged from 6 to 10 ft. approximately, the barge was built with sufficient depth in order that when sunk to the bottom, the deck would not be submerged, thus maintaining the necessary stability.

This type of drilling unit is known as a "Marsh Barge." These barges in the past were usually designed by the engineering staffs of oil companies or

drilling operators, consisting mostly of civil and petroleum engineers. However, when it was found necessary to proceed further from the shore line, the oil companies and drilling contractors soon realized that unknown and unfamiliar factors came into existence—namely, "the sea" with its tides, hurricanes, waves and variety of bottom conditions and other factors with which they were unfamiliar.

With the transition from land to sea, the oil industry realized that, in order to design and operate efficient and economical off-shore drilling equipment and attendant service craft, the services of Naval Architects and Marine Engineers would be required. On the other hand, the designer who stepped into this new field had to familiarize himself with the problems which confront the civil, petroleum and mechanical engineers of the oil industry. The designer had to realize he was dealing not only with soil conditions, but with the effect of waves on immovable structures so diametrically opposed to the condition imposed upon free floating hulls. The designer also had to learn about the machinery and materials required to drill wells to great depths, and last but not least to familiarize himself with the terminology of those who serve in the oil industries. Our firm was particularly lucky, due to its geographical location in New Orleans, almost within reach of and in the center of the offshore developments, to participate from the beginning in the offshore drilling and its engineering activities, and thus to help pioneer in the designing of offshore equipment such as portable drilling barges, platform tenders, personnel and supply vessels, etc.

At this stage before proceeding further, it may be of interest to discuss the criteria which govern and control the design. A storm in Holland dislodged a 20-ton block resting 12 ft. below the surface. In Scotland a breakwater weighing 1,350 tons, all its parts solidly bound together, was broken up and moved by the sea. These are good examples of what one can expect of the forces which act upon the offshore structures. As far back as Leonarda Da Vinci in the fifteenth century, these forces were the subject of study. It is not the aim of this article to go into details. Sufficient to say for our purpose, that the forces exerted by waves on obstacles with respect to their orbital motion and dimensions are represented by the equation, $P=C_d\ V^2$. Where P is Pressure in pounds per square foot, C is Drag Coefficient and V is the Velocity of the water. The Drag Coefficient depends upon the shape of the object while the wave characteristic depends upon the wind velocity, fetch and water depth. Recently Mr. Walter Monk and Mr. Joseph B. Kelly developed the solitary wave theory with the maximum impact at the breaking crest. For near breaking waves the Stoke-Struik theory is used, and for deep water waves the Airy Theory is used. For preliminary design an emperical formula $P=HC$ for Pressure on Circular Columns based on above-mentioned studies, was developed by our organization. P is the pressure at the crest of the wave in pounds per square foot, H is the height of the wave above the still water level and C is a Coefficient which is given in the table below:

For	H	C
	10′-20′	45
	20′-35′	36
	35′-45′	32.1
	45′-60′	30.5

The tools for the developing of the offshore oil fields can be subdivided into two groups. Group (1) permanent platform supported by piling, and Group (2) movable, floating, drilling units referred to in the majority of cases as portable drilling units or barges.

PLATFORMS

Group (1) Platforms until recently, had the advantage that only they could be used in deep water. A self-contained drilling platform has the working area of 200′ by 110′ approximately. The platform serviced by a tender may have the working area of 42 ft. x 66 ft. approximately. Briefly, for deep waters such a unit consists of a templet which is lowered in sections to the ocean bottom with its vertical members projecting above the water level. Steel pilings are driven through the templet legs into the soil as deep as 100 ft. or more. A platform with corresponding legs is superimposed on the templet and welded on. When in place, machinery, derrick, other equipment and supplies are installed and provided. When a tender is used for servicing a non-self sustained drilling platform, then only the derrick, drawworks and rotary table are installed on the platform. The balance of equipment and supplies such as source of operating power, cement, mud, fresh water, piping, casing and crew quarters are located on the tender. Until recently, the tenders used, were converted vessels. It was found that a ship most suitable for conversion with a minimum reasonable expenditure was a well-known World War II work horse, namely the L.S.T., which in large numbers were acquired in the past from the government by the oil industry, and the conversion cost of which ranges between $850,000 to $1,300,000 approximately. (See Figure 1).

The conversion is usually executed in accordance with the rules and regulations of the American Bureau of Shipping, U.S. Coast Guard and the U.S. Public Health Service requirements. The machinery and hull structures are completely overhauled. The existing quarters are modified and additional quarters provided in order to accommodate a total personnel of 60 to 125 men, working in two or three watches, spending two weeks aboard before shore leave. The generating plant is augmented by additional diesel generators of 100-120 K.W. capacity. Air conditioning is provided. Additional 5-ton booms with corresponding winches may be provided, and new 10,000 pound anchors and windlasses are installed. A helicopter deck is provided, and a working platform is erected on the bow with removable bridge leading to the drilling platform. Mud pits, cement units, hoppers, mud pumps, storage for cement, fresh water and pipe racks are provided on the vessel. Additional communication and hotel equipment are provided, and all other machinery, equipment, motors and pumps, a list of which is too lengthy to be enumerated but necessary for the service, are furnished as well.

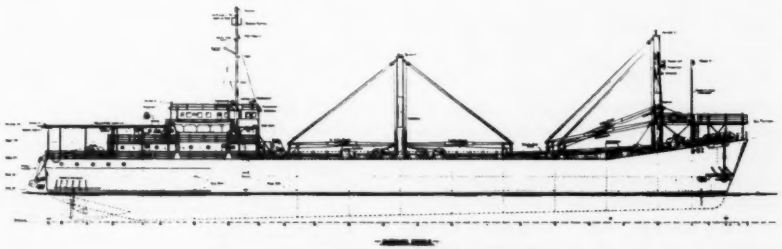

Figure 1. Converted Drilling Tender.

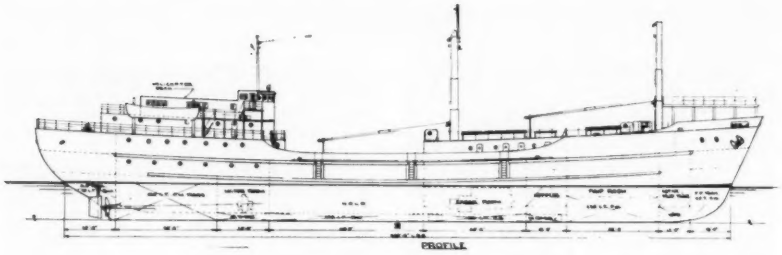

Figure 2. Latest Design Drilling Tender.

Since at present there are few LST's or other vessels suitable and available for conversion, new tenders must be built, and their designs prepared. (Figure 2).

Typical tenders would have the following approximate characteristics, which necessarily vary due to the various requirements set forth by the owners. A tender is not required to possess a high speed, and therefore fine lines are not a prerequisite.

A block coefficient of .72-.75 can be used. The length between perpendicular is 250 ft.-320 ft. approximately with a molded beam of 50-72 ft. with a draft of 12 ft.-16 ft. and a depth of 20 ft.-30 ft. The Dead Weight of the tender is 1840-3500 tons. An 1840 tons DW is composed of 300 tons of pipe, 200 tons of mud, 200 tons of cement and 900 tons of drilling fresh water and fuel oil. The crew for each tender including the drilling complement would be about 60. The propelling H.P. required is about 1500 to 3000 BHP with diesel generators of sufficient capacity for operating the drilling machinery.

Although until recent times the platforms supported by pilings were the only answer to the need of drilling in medium depths or deep water, they have several disadvantages. Should the velocity of the wind increase and the sea becomes rough, the service vessels must leave the location and run for safety, thus interrupting the drilling operation. In addition, an erected platform which may cost $300,000 approximately, excluding the cost of the drilling machinery, must be dismantled to the mud line if the site, due to a dry hole or exhausting, must be abandoned. Every time that a platform is dismantled, the salvage value is $300,000 or $400,000 in the red. Therefore, only by decreasing the time of erection or dismantling can the operator hope to save money. This can only be achieved by decreasing the number of "lifts" of component parts of the unit, with corresponding increase of "load" per each lift. Partially this can be accomplished by using a heavy-lift derrick barge, but even then, the time necessary for erection would be from 14-16 days, and during this period heavy weather may occur, thus prolonging time of the operation, sometimes up to 30 days approximately. In an effort to better the efficiency of construction, heavy lift revolving derrick barges were built. One such barge recently built has the following characteristics:

LOA .....300′-0″
Beam Molded. 90′-0″
Depth Molded 19′-0″
Boom Length. 200′-0″
Lift Capacity. 250 tons at 50-80′ length
Accommodations
for ..... 60.

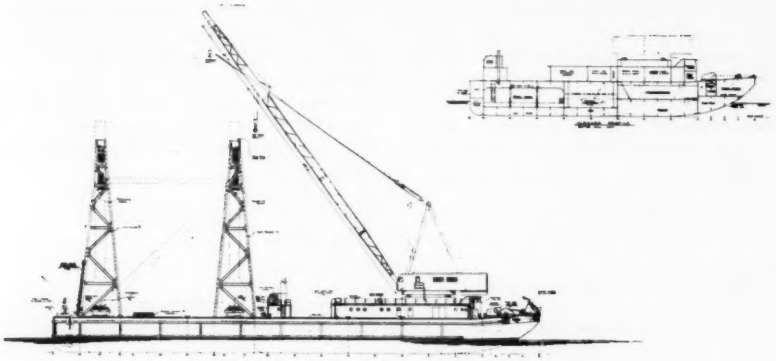

Figure 3. Transport & Erection Vessel.

At present derrick barges with greater lifting capacity are contemplated. Recently, in an effort to further cut down the overall expenditure, a vessel was designed and designated as "Transport & Erection Vessel" for erection of offshore drilling platforms and general heavy marine construction work in open-sea. (Figure 3). The vessel has the following characteristics:

Length Overall	290′
Beam Molded	120′
Slot Length	125′
Slot Width	75′
Accommodations for Crew of 60.	

The vessel consists of three sections bolted together, the outboard section forming the side of the erection slot where the drilling structure is transported and secured. On the port and starboard of the slot four (4) lifting towers are provided in order to lower and raise the drilling platform. The towers are completely equipped with the necessary machinery for a 4-point pick-up, consisting of traveling blocks, crown blocks, fairlead sheaves, winches and necessary cables. The total lifting capacity of all four (4) towers is 1200 tons, but they were designed for a 2,000 ton lift in order to provide for an uneven distribution of load. This lifting capacity is 3 to 4 times greater than any existing capacity of a derrick barge. This means that a platform complete with all drilling machinery can be fabricated on shore at a lesser cost. The construction economics are obvious since all the fabrication is done in the shipyard where the cost per man hour including overhead and profit is approximately $3.60, while a man hour necessary in order to obtain the same result is 2½ times more than above amount, when the fabrication work is done offshore. The structure is carried to the location and erected without loss of time in a depth of water up to 60 feet all *in one piece*. For water exceeding 60 feet up to 130 ft. approximately or more, the platform can be erected in two pieces—1st the templet and then the platform proper.

The above described vessel can be useful for military purposes as well, as it brings simplicity to the erection of radar towers or landing docks. The vessel has ample positive stability under all possible operating conditions. The horizontal thrust of the platform due to pitching and rolling while being transported is counteracted by hydraulically-operated rams. A revolving crane having a 20-ton capacity at 200′ length and 50-tons at 150′ is provided for handling piling and various other

loads. The power is supplied by four (4) diesel generators with each engine developing a minimum of 600 B.H.P. at 900 R.P.M. Air-conditioned crew quarters, mess room, galley, offices, recreation rooms, etc., are provided on board.

The financial disadvantages, in many cases, of fixed platforms, created a brand new line of thought, which resulted in the design of a portable drilling unit, which could be moved with minimum delay from one location to another as required. These units, which are really the further development of the "Marsh Barges," can be classified as follows:

PORTABLE DRILLING UNITS

These units can be subdivided into:

A. Fixed units, where the drilling platform is supported from a hull by means of fixed length columns.

B. This elevated deck unit consisting of a lower hull which is sunk to the bottom and an upper hull which is raised above the sea level after the lower hull is sunk, the upper hull becoming the drilling platform.

C. Elevated deck units, which instead of a lower hull utilizes large diameter casings in order to lift the floating hull, which forms the drilling platform above sea level.

D. Spud Barges.

Irrespective of the type of units, their size and dimensions must be such that they cover a wide range of depth of water. One type should be able to drill from 10-30 ft. of water, another type to drill from 30-75 ft. of water, and a third type to drill from 75-110 ft., all under hurricane conditions.

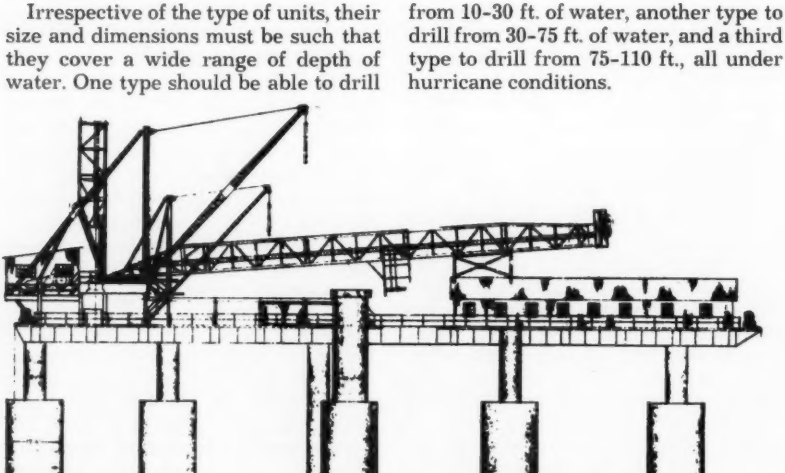

Figure 4. Early Type of Portable Drilling Unit.

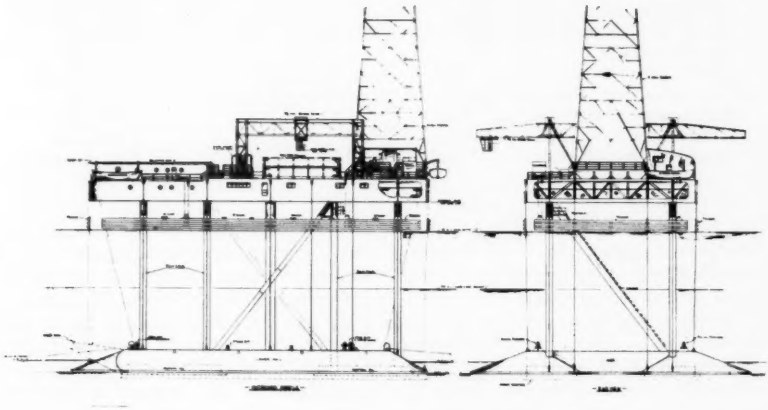

Figure 5. Latest Type F & G Portable Drilling Unit.

Of course, in the future it may be found necessary to design units which could drill beyond the 110 ft. depths. There are numerous types of units which can be used for drilling up to 60 ft. depths, but beyond this limit few designs are available. All existing fixed deck units which operate in relatively shallow waters have much in common. They consist of a hull, which is sunk to the bottom by ballasting, the drilling platform being supported above the water level by means of fixed columns. The critical moment occurs when the deck of the hull becomes submerged and loss of stability takes place. In order to prevent a disaster, several means are employed. Some units in shallow water are trimmed until their rake settles at the bottom. (Figure 4) and then the balance of the hull is flooded, thus causing the unit to settle down. Other units have pontoons located outboard of the columns supporting the drilling deck, or thus supplying the necessary water plane moment of inertia when the hull is lowered. These pontoons unfortunately provide additional resistance when the vessel is under tow.

A design was prepared and unit built, where recessed in the hull bottom; four pontoons are provided and are hydraulically depressed to the ocean bottom when the unit is on location. When they are in contact with the soil, the hull is ballasted and slides down being stabilized and guided by the ram columns which are attached to the pontoons. When lowered, the hull once more rests over the pontoon. To refloat the barge, the process is reversed, the average time necessary for the operation is about 4 hours. The control system is automatic and combined with pontoons, position indicators and sounding gear.

The following are the characteristics and a brief description of the above mentioned self-stabilized barge, which was designed to operate in 75 ft. of water: (Figure 5).

Characteristics

Length Overall	190′ - 0″
Beam Molded Including Anti-Scouring Wedges	150′ - 0″
Depth of Hull	12′ - 0″
Draft	6′ - 7′½″
Clearance from Hull to Underside of Elevated Drilling Deck	90′ - 0″
Slot Length and Width	36′ x 32′
Displacement	4532 tons
Range of Stability	31 degrees

The vessel is of all steel welded construction designed to ABS highest class assigned to this type of vessel. The vessel essentially consists of an elevated drilling platform and a barge type slotted hull. Port and starboard wedges, triangular in cross section are secured to the hull extending the whole length of the vessel. The purpose of these wedges is to provide additional stability when under tow and additional protection against scouring. For this purpose, the wedges have at the lower edge a 4 ft. deep lip which penetrates into the mud. The forward end of the hull is equipped with a movable hinged section which serves as rake when the vessel is under tow; when lowered during the drilling operation, it serves as additional protection against scouring. The hull, port and starboard wedges are compartmented into ballast, drilling water and potable water, fuel oil tanks and pump room and void spaces. The pumps located in the barge hull are operated by remote control from the elevated platform. The elevated deck is supported by 10 columns, the underside of the deck being 90 ft. above the barge. Eight (8) supporting columns are utilized for the hydraulic system which raises and lowers the pontoons. These columns are 42 inches in diameter. Two columns 60 inches in diameter are utilized for access from the elevated deck into the barge pump room. One of these columns is equipped with an elevator and the other contains pipes, vents, etc., and serves as an auxiliary escape as well. A number of diagonal tubes are fitted to brace up the column structural system. Fenders, adjustable for various waterlines are provided at the ends and port and starboard sides of the vessel. On the elevated platform consisting of three (3) decks, air conditioned crew quarters for 80, cement equipment, sand traps and anchor winches, mud pits, material storage, cement, mud hoppers, as well as the necessary machinery are provided. The top of the deck house serves as a helicopter landing deck. Necessary access hatches, ladders, etc., are provided throughout the vessel for access and operation. All machinery and pumps are electrically driven, the power being supplied by two diesel generator sets. To prevent corrosion the columns for 40 ft. of their length are wrapped with stainless steel and Cathodic protection is used for the hull.

A unit designed for use in shallower up to 30 ft. depth waters is essentially based on the same principle and is less expensive. It has the following characteristics:

LOA	156′-0″
Beam	90′-0″
Depth	11′-0″
Slot	35′-3″ x 12′-6″
Drilling Platform	140′ x 60′
Crew Accommodations for 4	

Now that portable drilling units which can drill in 75-80 ft. of water in good weather conditions have been outlined, we can discuss the units which drill in water deeper than 80 up

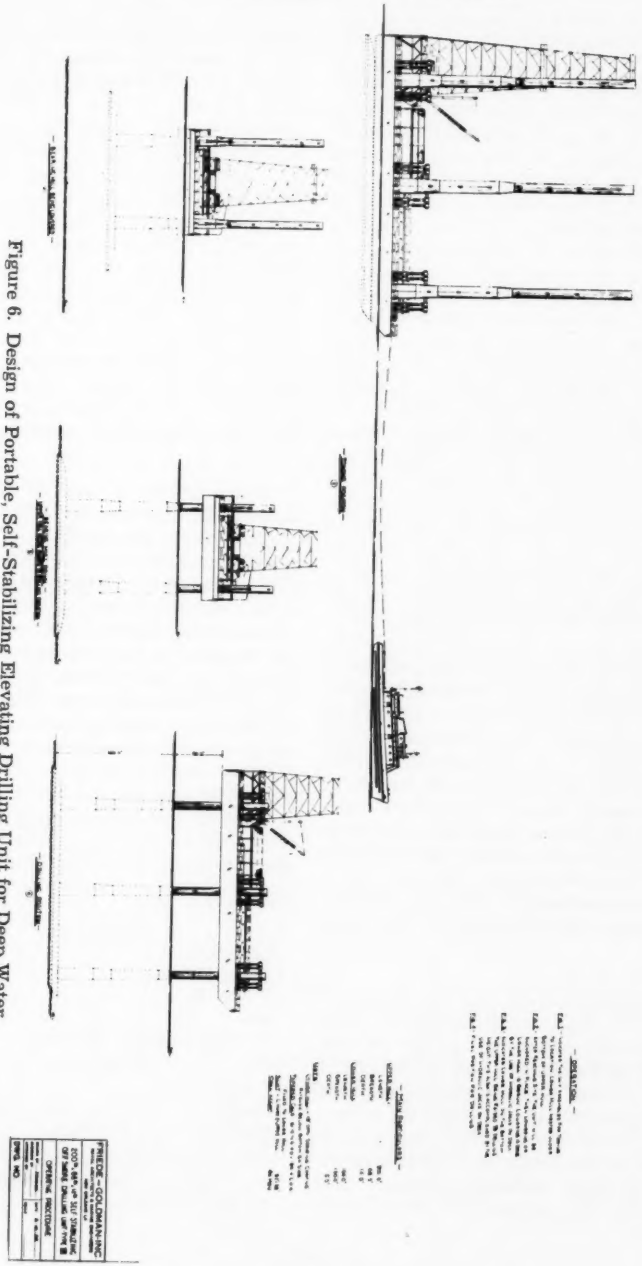

Figure 6. Design of Portable, Self-Stabilizing Elevating Drilling Unit for Deep Water.

to 120 ft. not only during good weather but in hurricane conditions when a 45 ft. clearance is needed between still-water level and underside of drilling platform, in order to clear the crest of waves. As far as the author knows, there are only at present three (3) types of units which were designed to fill such requirements. One type utilizes piling as a stabilizing medium sending the lower hull to the bottom only after the pilings are driven in. The second type unit consists of a hull and movable tubular casings each operated by an air jack. The lower end of each casing terminates with a cylinder which penetrates into the bottom and provides necessary resistance. When the bottom of each of the casings is securely embedded in the soil, the barge hull by utilizing the same air jack begins to rise into the air and at a desired height is secured in position, thus forming the drilling platform. A third type, referred to as Type VII, is based on a spread footing foundation when in drilling position. The unit is completely self-contained, and designed to work in depths up to 120 ft. of water. (Figure 6). When on the bottom, the lower hull exerts pressure of approximately 255 pounds per sq. ft. This unit utilized the conception of two (2) hulls, the lower hull nesting in the upper hull when afloat. This lower hull is depressed to the bottom and, without interrupting the cycle of operation after the lower hull makes contact with the bottom, the upper hull rises above the water level.

The lower hull is only 5 ft. deep, and since its edges are streamlined, it reduces the horizontal thrust of the waves at the bottom, and having on the edge a lower lip projecting and penetrating beyond the mud line the scouring is minimized. When the hull is raised to the required height, it forms the drilling platform. Raising and lowering the upper and lower hulls respectively is achieved by hydraulic means, utilizing sea water as the hydraulic fluid. The hydraulic jacks provide a positive type of grip which eliminates the necessity of using clamps, which gouge the steel column and weaken it. Failures of this type have been recorded in the past where the columns were previously damaged by clamps. Failure occurred at a much lower stress than that for which they were designed. The jacks have a 40 ft. stroke, thus reducing the number of connection set-ups required, as well as the time required to pass through the dangerous area where the lower hull comes in contact with the ground and the upper hull is first raised out of the water.

Each column is tapered from the bottom to the top. Its diameter is largest where the bending moment is greatest and smallest where it is lowest. Also, the wave force at the bottom where the columns are 10 ft. in diameter is approximately 300 pounds per sq. ft. against a force of more than 1000 pounds per sq. ft. where the columns are only 6 ft. in diameter. This tapering reduces the tipping moment of the barge, the amount of steel required per column, and the increase in soil pressure. The unit has the following characteristics and DW carrying capacity. This DW does not interfere with the stability when undertow (Figure 6).

Characteristics

Upper Hull

Length O.A.	200′-0″
Beam Molded	88′-0″
Depth Molded	14′-0″
Slot	32′x38′
Accommodations—40 men	

Lower Hull

Length	180′-0″
Beam	150′-0″
Depth	5′-0″

D.W. Capacity

1. 15,000 ft. of drill stem, 4-½″
2. 300 ft. of surface casing

3. 1000 sacks of cement
4. 2000 barrels of dry mud
5. 2000 barrels of fresh water
6. 1000 barrels of fuel oil
7. Crew—40

It may be of interest to note that Type VII unit with modification such as elimination of drilling slot and changes in dimensions may be utilized as a non-propelled tender in connection with a small drilling platforms. Although the slope of the continental shelf is mainly only about 10 ft. per mile, unfortunately this condition may not prevail on other locations. However, due to the fact that the columns are of special design, a much steeper declivity can be taken care of, thus making it possible to utilize Type VII for other purposes, such as anti-aircraft gun platforms, radar towers, loading docks, etc.

In shallow sheltered water, such as found in Lake Caddo in Louisiana and Lake Maracaibo in Venezuela, spud drilling barges can be utilized. These barges are held in place by retractable spuds. The hull is clamped to them and is ballasted as required in order to compensate and to be adjusted to the variation of water level. A small unit may have the following characteristics: (Figure 7).

LOA	80′-0″
Beam Molded	40′-0″
Depth Molded	7′-0″
Slot	26′-3″ x 8′-0″
Number of Spuds	8

The offshore drilling operations require an extensive auxiliary fleet. Some vessels are used as tugs, supply vessels and water tenders, and others are used as personnel transport vessels. Since the drilling units are being moved further and further from shore, these vessels must possess sea-going characteristics, thus superseding make-shift crafts presently used. A typical all-around purpose vessel would be a craft about 130 ft. O.A. length to 32 ft. beam with a 7 ft. draft approximately. It would carry an operation crew of 10, with a dead weight capacity of 340 to 350 tons.

The dead weight is composed of fresh drilling water in tanks under the deck, drilling pipes and casings as deck cargo, accommodations for 15 to 20 members of the drilling crew reporting from shore leave, and fuel oil and potable water for drilling operation. These vessels can be used also as auxiliary tugs to move platforms from location to location. In other words, the design of these vessels must suit various conditions and fit into various requirements.

In preparing this article, the author has had to draw heavily upon the developments and designs made by his firm, for which assistance he is indebted.

Unfortunately, the article does not cover in detail this new phase of designing, as it would require too much space, however, it is hoped that this brief description of offshore drilling activities may prove of interest to those who may in the future come into contact with this work.

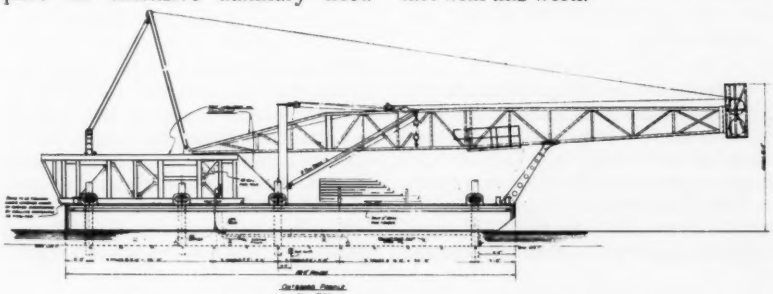

Figure 7. Shallow Water, Self-Elevating Spud Drilling Unit.

EVALUATION OF A NAVAL GAS TURBINE ENGINE

ACKNOWLEDGEMENT

This paper was presented at the American Society of Mechanical Engineers' Diamond Jubilee Spring Meeting in Baltimore, April 18-22, 1955. Its authors are John A. Culver of the Bureau of Ships, Navy Department, and Amos L. Wood of the Boeing Airplane Company, Seattle, Washington.

INTRODUCTION

The reasons why the Boeing model 502-6 gas turbine engine was chosen to power the minesweeping generator gear of the MSB should first be reviewed in order to report the service experience to date. Reason one was low cubic volume of the combined installation; reason two was total low weight since the boat was designed for hoisting aboard ships; reason three was efficiency and simplicity of control system to handle intermittent loads; reason four was low magnetic signature. The relatively high specific fuel consumption of this engine was not considered a serious disadvantage since the duration of any mission was relatively short.

A brief history and description of this equipment is in order to acquaint all with this installation. The gas producer section of the Boeing model 502 engine was designed in 1945 and tested in 1946. The complete engine was first run in June 1947. In that year considerable interest in this gas turbine engine was shown by the Defense Department. In 1948, a development contract with the Bureau of Ships was consummated. The model 502-6 was put into production for the MSB-5 Class Minesweeper application in 1950.

The generators, see Figure 1, are special duty units designed for minesweeping requirements. A small 120 volt ships service generator and amplidyne is mounted "piggy back" on the top of and belt-driven from the shaft of the main generator. This small generator supplies 120 volt power to special winches and a cable reel on deck but is not used for general ships service lighting and power. General ships service power and lighting is supplied by a generator driven by the main propulsion engines. The combining reduction gear is a double helical type (1). Normal input shaft speed is 2750 RPM with an output shaft speed of 2000 RPM. Each input shaft of the combining gear is attached to a Boeing 502-6 gas turbine engine through a

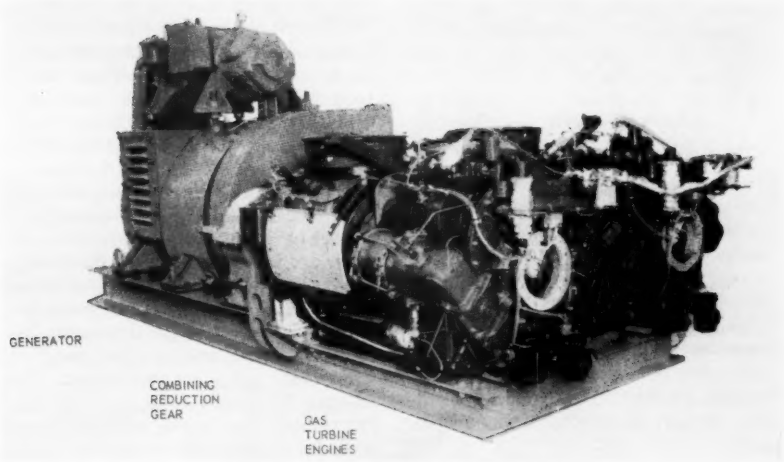

Figure 1. Gas Turbine Generator Set.

flexible coupling and over-running clutch, see Figure 2. The engines are each rated at 160 BHP.

The compressor is a single stage centrifugal type having a nominal pressure ratio of 3 to 1 with an air flow of 3.5 pounds per second. There are two through-flow type burners with a connecting cross fire tube. The first stage turbine directly connected to the compressor impeller forms the gas producing section. The first stage rotor turns at 36,500 RPM normal maximum. The second stage turbine is gas connected only, turning at 23,725 RPM normal maximum. The engine reduction gear ratio of 8.62 to 1 gives an output shaft RPM of 2750 at normal maximum.

The accessories required for these engines are:

1. A common electric driven fuel boost pump for the four engines installed.

2. An engine driven accessory drive accommodating a starter, fuel pump and governor assembly, lube oil pump and tachometer generator.

The accessories required for the combining gear are:

1. Speed control governor
2. Lube oil pump
3. Scavenge pump
4. Tachometer generator

SUPPORT PROGRAM

The Gas Turbine Support consists of spare parts, special tools, handbooks, field service, training, field change kits and engine overhaul, all of which appear to adequately meet Fleet requirements. The repair parts svstem to support MSB activities is somewhat different from that used with other Naval vessels. There are thirty-eight small repair parts carried on board each boat. These parts consist of items such as combustion chamber liners, fuel pump and governor assemblies, igniter plugs, gaskets, etc. There are thirty-two remaining repair parts maintained ashore, which consist of items that cannot be carried on board due to the lack of storage facilities.

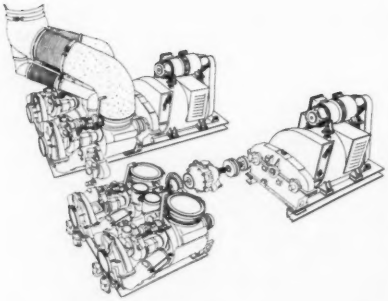

Figure 2. Gas Turbine Attachment to Generator.

There are 240 stock repair parts in the Navy Supply System to support repair parts.

There are no special tools required for normal fleet maintenance. Overhaul tools are limited to twelve items, all of which are supplied in a canvas bag. Handbooks prepared to Naval specifications were delivered concurrently with delivery of turbine generator sets. Boeing Field Service Engineers work directly with Atlantic and Pacific Fleet Operation and Maintenance personnel. Field Service Engineering unsatisfactory reports are converted into corrective or preventive action as directed by the Bureau of Ships or requested by Boeing Airplane Company.

Training of Naval Instructors for the U. S. Naval Training School was conducted at the contractor's plant under the direction of its Service Department. Certain service bulletin kits have been provided to the Fleet. A total of 31 contractor service bulletins have been prepared, most of which are now incorporated in all engines on the MSB boats.

One of the design objectives for these engines was an overhaul life of 1000 hours. The present established replacement period is 500 hours; however, the engines of the first five MSBs are being removed at 300 hours of operation and returned to the contractor for inspection, overhaul and repair as required. Replacement engines are installed from the Navy Supply System. The 300 hour overhaul period was authorized because these engines were not fully developed before installation and no prototype MSB was made prior to production. This interim 300 hour period gives the contractor and the Bureau of Ships a good basis for determining operational limits and a guide for design improvements. Already a study has been undertaken in conjunction with the overhaul program to determine if any performance deterioration takes place at 300, 500, 800 or 1000 hours of operation. All future design improvements of this model engine will be evaluated against these results. The Bureau of Ships has also directed an acceleration service test to be conducted by the Fleet. This was undertaken because the Generator Sets are used only a small portion of the time the boats are underway and operational hours were accumulating slowly. To date eight engines have gone 500 hours without incident. It appears that the original design objective of 1000 hour overhaul life is realistic and may be achieved with continued emphasis on reliability analysis, the resulting component design improvements, test cell development and confirmation by field experience.

FORCED OUTAGES

The basic engine weighs 252 pounds and is 42.9 inches long, 23.2 inches wide and 23.3 inches high. The unit itself is readily inspected or maintained however, the manner in which the engines have been packaged below the pilot house of the MSB leaves very little space for work to be ac-

complished on any of the equipment installed. Field information indicates that one engine was removed and disassembled for inspection by the operating personnel in six hours. With a crew of four men, the four engines can be removed in eight hours, and replacement engines installed ready for starting in an additional 20 hours. At present, the operating forces are not authorized to make repairs to high speed rotating parts and their casings; however, they may replace the damaged part with stock components.

There are a few points that should be clarified before forced outage data is presented. These engines were installed in the vessels without a prototype installation due to the high priority assigned to minesweeping resulting from the Korean affair. The engines were procured before the required 500 hour test run was completed. Today there is a component improvement program in effect to improve life and reliability of a few of the smaller components. The failure data included herein will be considerably improved when the improved components are incorporated on the sets.

A table of general information, see Table I, is now presented. The first MSB-5 Class minesweeper was turned over to the Navy in November 1952. The number of vessels included in this paper are fleet operational units only.

The overhaul time is the actual down time, (excluding shipment time to the contractor's plant) for disassembly, inspection, repairs, replacement and reassembly. The parts that are replaced are repaired, if possible, and placed back into bins for use in other engines. If they are beyond repair, the part is scrapped and a new part procured.

Forced outages are defined as the operating hours lost because of a shutdown caused by a failure of some engine component while the engine is operating, or failure to start when needed. The most serious forced outage to these engines is a failure that results in the necessity of removing the engine from the vessel and installing a replacement engine in order to keep the generator equipment available for operation. The number of hours required to remove an engine and install a replacement engine will be included in the actual down time due to the forced outage. The only assumption that will be made is that two men are used for the removal and installation. Failures that caused forced outages and engine replacement are as follows:

1. The overrunning clutch failed causing damage to the second stage turbine and reduction gear during single engine operation. The outage time was 35 hours.

2. Excess thrust bearing clearance caused severe scoring to the second stage turbine blades. The outage time was 35 hours.

TABLE I

Reporting Period (November 1952 through December 1954)	26 months
Number of Vessels (MSBs)	43
Number of Engines per Vessel	4
Total Number of Engines in Service	172
Total Hours of Operation (all vessels)	19,933*hours
Period between manufacturer's overhaul	500 hours
Number of forced outages	78
Ovehaul time in hours (actual down time)	1,500 hours
Routine Maintenance	2,178 hours
Routine inspection and tests	2,488 hours

* 20,000 hours will be used for the data herein.

3. A first stage turbine blade failure. The outage time was 15 hours.

4. First stage turbine blade failure. The outage time was 120 hours.

5. First stage turbine blade failure. The outage time was 15 hours.

Table II shows the total hours of all engines that were forced out due to some failure as reported to Bureau of Ships or obtained from the Contractor's Field Service Engineers. The forced outage hours divided by the total operating hours gives a 4.58 percent forced outage.

TABLE II—FORCED OUTAGES

Item	No. of Failures	Hours Lost Per Failure	Total Forced Outages (Hours)
Accessory Drive Gear	12	31.3	375.6
Igniter Plug	11	1.8	19.8
Overspeed Switch	11	0.5	5.5
Starter	8	7.8	62.4
Fuel Pump and Governor	5	5.0	25.0
Turbine Failures	5	44.0	220.0
Oil Pressure Switch	3	0.4	1.2
Exhaust Thermo Switch	2	0.3	0.6
Oil Pressure Switch	3	0.4	1.2
Fuel and Oil Leaks	3	0.8	2.4
Speed Control Governor	3	6.6	19.8
Exhaust Thermo Switch	2	0.3	0.6
Fuel Solenoid Valve	1	0.5	0.5
Tachometer Generator	1	0.5	0.5
Combining Gear Oil Seal	1	24.0	24.0
Waste Gate Assembly	1	4.0	4.0
	78		916.1

SCHEDULED OUTAGES

Scheduled outages consist of routine inspections and tests, routine replacements and repairs, overhaul down time and engine removal time. In the MSB program the average number of man-hours for scheduled routine inspections and tests has been reported by operating forces as four hours per month per boat. For the period this paper covers, the total routine inspections and tests then amount to 622 boat months or 2488 hours.

As the result of the above routine inspections which are necessary as preventive measures, some parts are determined as requiring replacement or repair. Table III records the routine replacements and repair.

The overhaul down time has previously been explained. The labor for this scheduled outage is 250 man-hours. With two men working the outage time is 125 hours per engine. Twelve engines have been returned to the contractor for overhaul which gives 1500 schedule outage hours.

The time required to remove the engines from the boat is decreasing as more experience is gained by the operating forces. The reported figures vary considerably; however, an average figure is 300 man-hours with three men working to remove the old engines and reinstall and qualify replacement engines. The outage time is

TABLE III—ROUTINE REPLACEMENTS AND REPAIR

Item	Total No. Replaced or Repaired	Hours to Replace Including Repair	Scheduled Outage
Starter Retrofit Kit	172	3	516
Accessory Drive Gear	138	6	828
Burner Liners	102	2	204
Fuel Control Governor	26	2	52
Starters	21	10	210
Igniter Plugs	15	1	15
Thermo Switch	15	1	15
Oil Pressure Switch	12	1	12
Overspeed Switch	12	1	12
Cross Fire Tube	10	2	20
Speed Control Governor	10	6	60
Inter Stage Bleed Valve	9	4	36
Accessory Drive Units	9	12	108
Over Running Clutch	6	4	24
Fuel Solenoid Valve	6	1	6
Fuel Nozzle	4	2	8
Starter Relay	4	1	4
Reduction Unit	3	3	9
Thermocouples	3	1	3
Oil Temp Switch	3	1	3
Ignition Boost Coil	3	1	3
Lub Oil Pump	3	4	12
Tach Generator	2	1	2
Compressor Case	1	16	16
	589		2,178

then 100 hours per boat. Three boats have gone through this procedure, therefore, 300 scheduled outage hours will be added.

All scheduled outages discussed above total as below:

Routine Inspections and Tests (from Fleet)	2488 Hours
Routine Replacements and Repairs (from Table III)	2178 Hours
Overhaul Down Time (12 Engines)	1500 Hours
Engine Removals	300 Hours
	6466 Hours

SUMMARY

The forced outage data (Table II) is a good key to engine reliability. From this study the model 502 installed in the MSB has been reliable 95.4% in its operation. In analyzing the cause of failure, the Bureau of Ships and Boeing find themselves in an excellent position to correct the causes of failure that result in forced outage time. These engines were watched closely in the early stages of the program; and as a series of troubles occurred, they were studied and, in most cases, corrected by design changes or modifications. Many engines were modified before the MSBs were delivered to the Navy.

Regarding the accessory drive gears, these units have the highest forced outage time. The material in one gear

was changed and the unsatisfactory reports have stopped. If life tests on the engines were completed before deliveries and installation, this failure would not have occurred.

First and second stage turbines account for 220 forced outage hours. The turbines were expected to give the most trouble; however, they have held up very well under repeated heat cycles. Engine serials 53, 132 and 222 had first stage blade failure at 361, 46 and 113 operating hours respectively. The engines were shipped to the contractor for a detailed analysis of the failures and overhaul of the engines. The analysis is not completed as yet; however, the Bureau of Ships has authorized a wider chord blade for the first stage turbines. The wider chord blade may cut down this type failure. On engine serial 58, the overrunning clutch locked in the engaged position. When the mating engine was started for single engine operation, it dragged the power turbine of engine 58. No lubrication is provided the second stage reduction unit unless the gas producer section is running. New design overrunning clutches are presently on test at Boeing. On engine serial 106, the press fit between the shaft and turbine hub failed causing thrust clearance which resulted in severe scoring to the second stage turbine blades. The cause of failure is still being studied by the contractor.

The wiring failure outage indicated in Table II occurred on one boat only. A wiring fault caused the grounded gas turbine wiring to burn out. This occurred three times before the trouble was isolated. This was an individual ship problem, therefore no design change was necessary.

A program to increase life and reliability of engines and components was established soon after delivery of the first boat. Development work and testing is in progress by the contractor on the following components:

Second stage governor
Oil pressure switch
Overrunning clutch
Ignitor plug
Fuel pump and governor
Starter
Burner liner
Crossfire tube

The remaining items not covered above are relatively few in number and will receive second priority development effort.

A review of Table III indicates that the routine maintenance hours appear

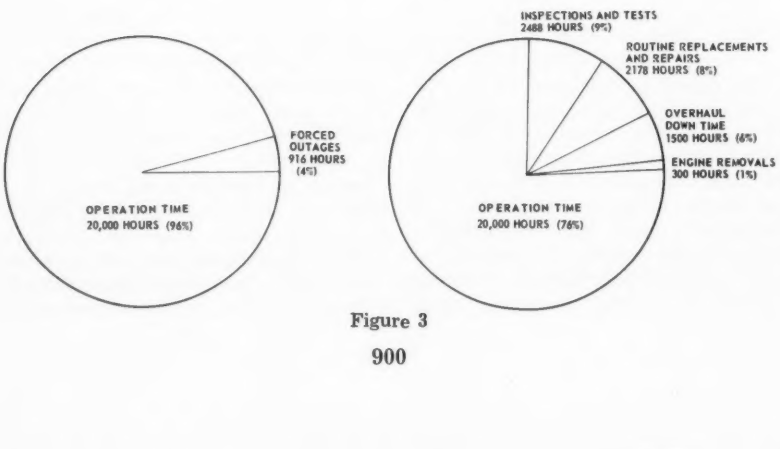
TOTAL OPERATION TIME
FORCED OUTAGES 916 HOURS (4%)
OPERATION TIME 20,000 HOURS (96%)
TOTAL MAINTENANCE TIME
INSPECTIONS AND TESTS 2488 HOURS (9%)
ROUTINE REPLACEMENTS AND REPAIRS 2178 HOURS (8%)
OVERHAUL DOWN TIME 1500 HOURS (6%)
ENGINE REMOVALS 300 HOURS (1%)
OPERATION TIME 20,000 HOURS (76%)

Figure 3

high. Perhaps a decrease in the number of inspections and tests will come as the program progresses and more experience is gained by maintenance personnel. The hours for overhaul will decrease as larger quantities of engines pass through the overhaul activity. All of this taken collectively will decrease the scheduled outage hours.

Figure 3, Charts of Operation and Maintenance Time, shows a compilation of the data acquired in this paper. Although the relative percentages of some of the items in this total may not be comparable to each other, any single item can be compared to the whole of this study.

So far the authors have only summarized troubles. Certain successes should be noted. First and foremost, Boeing gas turbine program appears adequately supported in all of its phases. Spare parts and field service engineers are in the field and an overhaul program is in being. Training is underway and over 800 handbooks have been distributed. The gas turbine operation has been good. Airborne noise levels were reduced to acceptable limits (2). High ambient temperatures have not compromised the ability of the engines to meet the required loads (3). The free turbine configuration of the model 502 has proved itself in meeting the required load schedule (4). No compressor surge or bearing failures have occurred in which damage was caused to any MSB boat. The turbine blades which failed have passed out the exhaust stack. One even landed on deck and was forwarded to the contractor for examination.

In final summary, the trends gathered from the present data are reasonably clear. The authors expect to make another check at approximately 100,000 hours of operation and at that time these trends can be more definitely established.

CONCLUSIONS

Items causing forced outages are being corrected and in some cases modifications have been completed on installed engines.

By increasing the life and reliability of the components, the forced outage time will decrease and should approach 1% (5). Engine reliability will increase beyond its present 95.4%.

Coincident with the reduction in forced outage time the hours required for routine maintenance will also reduce because of their interrelationship.

Forced and scheduled outage data indicate good reliability for this gas turbine engine in this particular application.

There have been many "growing pains" in the development of prime movers, some of which took many years to overcome. This engine is still in the growing pain stage, yet shows comparative reliability with other engine types. The Bureau of Ships has a contract with Boeing to improve the fuel consumption by improved design, higher turbine and compressor efficiencies and higher compressor pressure ratios.

This paper gives factual data for a given gas turbine engine in a given Naval application. It points out that the reliability of this small engine is competitive. With continued development to better its components and accessories, this engine will be more acceptable in an increasing number of applications.

ACKNOWLEDGMENTS

The authors greatly appreciate the able assistance and suggestions of Lt. W. L. Strong of Mine Squadron 10, and I. E. Jackson, Jr. of the Bureau of Ships.

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HOW TO IMPROVE YOUR SHIPYARD OVERHAUL

COMMANDER ROBERT J. KNOX, U.S.N.

THE AUTHOR

graduated from the U. S. Naval Academy December 19, 1941. He served as Engineer Officer of the USS *MacLeish* (DD220) and the USS *Hunt* (DD674); in the latter he also served as Executive Officer. In June 1948 he received his Master's degree in Mechanical Engineering from the U. S. Naval Postgraduate School, and began working with the USS *Timmerman* experimental machinery at the U. S. Naval Boiler and Turbine Laboratory, then the Supervisor of Shipbuilding, Bath, Maine and finally as Engineer Officer of the USS *Timmerman*. In July, 1954, after three months as a ship superintendent, he became the Destroyer Type desk in the Boston Naval Shipyard, and in May, 1955, he became the Shop Superintendent.

Many of the ship's officers who arrive in the shipyard for a regular overhaul lack the experience which is necessary to get the most for their time and money. This conclusion was expressed by one of the commanders of a destroyer squadron which recently underwent an overhaul at the Boston Naval Shipyard. He suggested that I hold school on ship's officers on their arrival in the shipyard. As an example of the need for such schooling, the squadron commander remarked he had overheard a junior officer say that he was going to tell a Leadingman to investigate the shortcomings of his Quarterman. It was obvious by his tone of voice that he thought the Quarterman worked for the Leadingman.

These so called indoctrination lectures have been well received. As a rule the commanding officer and 75% of his officers attend the lecture which often approaches the three hour mark. The officers have frequently turned down a five minute break to permit the lecture to continue, which seems to indicate that the material must be new and of interest to them.

Let me assume you are coming into a repair activity for an overhaul. I will try to speak frankly and to express my personal conclusions on how you can get the most for your time and money during a regular shipyard availability. My conclusions are drawn primarily from eighteen months experience as a chief engineer of a destroyer under

continuous overhaul, one tour of duty as a ship's superintendent of a destroyer escort, and six months as Planning and Estimating Assistant (Type Desk) for small combatant vessels—all, in the same shipyard. As you can see, it is a unique experience which forms the basis for this article.

All repair activities are organized and operated along the same general principles. All vessels are not much more than big or little destroyers. The following comments, therefore, should have value to any vessel about to undergo an overhaul of any length.

ESTABLISH GOOD RELATIONS

It is not necessary to pass out hams, coffee, or foul weather jackets. Act like a sucker and you'll be treated like a sucker. The average shipyard worker is a good guy. He maneuvers at times because his first interest is the wife and kids at home and their livelihood. As you contact shipyard workers, you will learn that they are human beings. Treat them as human beings. They have pride and they have feelings. They can like and dsilike people for the same reasons as you and I. They can respect a man or they can spot a misfit, a malcontent or a disinterested officer, chief, or sailor.

Be honest. It may sound peculiar that I should even have to mention it among men, but it seems necessary. At times we get carried away by enthusiasm or other similar forces and we have a tendency to deal in half truths. It accomplishes little other than to break down our good relations, mutual confidence, and trust.

Don't be too quick to criticize. Sure, there are bums in a shipyard. There are bums in the Navy too. Every outfit has its bums. There are always a few who slide by. In general, though, if you follow your jobs with interest, the work will be accomplished with interest. Walk through the ship and inspect your jobs in progress. Know each job by sight and know the condition of it. A half hour walk twice a day can do the trick. When I was a young ensign, an outstanding officer I worked for said, "Bobby, inspect your jobs. That khaki uniform does wonders. You may not have the slightest idea at what you're looking, but the worker can't be sure—you might know. As a result, you'll get better work."

PUSH YOUR JOBS

Keep pushing your jobs. First, get all the "open and inspect" jobs moving. An "open and inspect" job cannot be inspected until it is opened. A list of parts must then be made, then ordered, then received, then installed and finally the unit tested. No one can be sure of the time element until the equipment passes a satisfactory test. If the jobs don't move, "scream" until they do. The ship superintendent won't be happy about it, but everyone will be happier by the time the last week of the availability comes around. Also, if the shipyard knows what is on your mind, we can keep you happy.

Next, push for all jobs to be started and then push for their completion. Some people say, "Sign off your jobs as soon as possible so you can recover your money." Fiddle-sticks. Sign off your jobs as soon as you can so as to force the shipyard off your ship. The shipyard is trying to do the same thing, but this dual effort is necessary.

Another reason for pushing jobs to completion, and then signing off, is to reduce the number of jobs you must follow. At the early part of the overhaul, you are only interested in a job getting started. During the middle

period, you are primarily concerned with keeping all jobs moving. After the half way mark, you begin to get interested in details. Your mental capacity has a limit, so it is only good sense to reduce the jobs to a minimum to permit you to become familiar with details on each job. During the last two or three weeks, the commanding officer should be well-acquainted with every job still in progress and it's controlling factor.

A third good reason to try to sign off jobs early, is to improve your inspection. Can you imagine signing off one hundred to two hundred job orders the last week? If you do, you'll lose. Here's how it generally works. The ship's superintendent or commanding officer will ask the department head if a certain job can be signed off. "Yes it can—well, I'm pretty sure, but let me check." This same exchange of comments goes on between department head and division officer, division officer and chief petty officer, chief petty officer and 1st class in charge of the equipment. The job is complete *EXCEPT* the laggers haven't lagged the line, or the brackets aren't on the line, or the welder hasn't welded the bracket to the bulkhead. It is not unusual for a small job to take a week to finish the last 5% of the job. If the push is started early, all these details can be cleaned off. If the push starts late, too many people are under pressure and jobs are signed off as 100% when they are actually only 95%. Two weeks later and 1000 miles away, the vessel discovers the incomplete jobs and the shipyard is cursed for turning out poor work. Granted the shipyard should be cursed, but that doesn't help you 1000 miles away.

Another reason to push jobs, particularly on operation equipment, is to get an early test. Don't run the test one hour or four hours and wrap the equipment in moth balls until your departure. Go out and take a look at that pier and play like you are at sea. Operate your equipment for twenty-four or forty-eight hours. Run it long enough that if it is going to fail it will do so alongside the pier rather than in the channel as you head to sea. Then, if a bearing is installed so that the oil goes out when it should go in, you can notify the ship's superintendent of the difficulty. The job will be rectified. If you don't run the equipment until you leave and then it fails, we all suffer. You, on the other hand, must do the work entirely with ship's force under adverse conditions.

PASS THE WORD ALONG

Job orders are issued to the ship in sufficient number so the skipper can have his copy to eat, throw away or file under his mattress. The ship's liaison officer should pull a copy and keep the master file. The department head can have his copy and pass the remaining copies along within his department. Keep an accurate, up to date file of these jobs by job order number. Read the job carefully. If it says what you want, then the ship superintendent must be sure Production does that work. If it does not say what you want, contact Planning (Type Desk) and have the job revised.

FOLLOW THE PROGRESS OF WORK

I was talking with a mechanic named Jerry one day, a top notch machinist if there ever was one. Jerry said, "Gee, tomorrow I gotta go over on the *Blackfoot* and work. I hate to go there. It's dirty and nobody gives a damn." I in-

quired how come, where was the chief engineer? "I don't know," replied Jerry, "I've never seen him."

A fine overhaul that ship will get! What will be the reaction of the ship when they leave? It will be, "What a lousy yard that shipyard was at Boston."

It is generally agreed that the best overhaul will go to the ship which most carefully follows the progress of work. The best method seems to be that in which the commanding officer meets each week with his department heads and the ship's superintendent and goes over each job. Has the job started? Has progress been made since last week? Why not? Is the material on order? When is it due? When can we expect the report from design? What does the Type Desk say? Pin each job down.

The first couple weeks the members of the conference will be like bear cubs in a pepper factory with boxing gloves on all four feet. Their charts will generally be disorganized or beautiful and useless. Two people will list the same job, while other jobs will be listed by no one. After three or four weeks things will begin to click. It will begin to be ambarrassing if a man must tell the commanding officer two weeks in a row that he doesn't know the status of a job. To avoid this embarrassment, the questions will flow down the line to the 1st class in charge of the equipment. The result is constant, close, and interested supervision of shipyard work along the entire chain of command. Why the need for this supervision? Isn't the yard supposed to do a job 100%? You are absolutely right, but it isn't as ideal as all that. Perfection is the goal of everyone, but in the interim you must face reality. You're in for an overhaul and your next chance comes two years hence. After you leave, you'll pay for your sins or reap the reward for your efforts.

CLEAN UP THE SHIP

It is surprising the number of people who feel, "Your time in the shipyard is the time when you are supposed to be dirty." Nothing could be farther from the truth. Safety alone is sufficient reason for promptly removing all scrap and excess material from the ship. Methods vary with each ship, but there is no justifiable excuse for a ship being dirty and cluttered because the ship and the ship's superintendent cannot agree as to a method of cleaning and a line of responsibility.

Ships are always eager to gain a few dollars on a job so they can get another job issued. Surprisingly enough, many do not realize that a cluttered ship costs them money. Certain doors or hatches can be blocked off which require workers (and ship's personnel) to detour through several spaces to reach a job just beyond the barrier. In confined spaces, equipment scattered around can make work almost impossible. It can also make fire-fighting impossible.

Filth begets filth. I have seen an empty milk carton and a pile of orange peels in a fireroom in the morning. By afternoon they had been joined by a rumpled paper lunch bag and a banana skin. The pile will grow if it isn't removed. In contrast I have also seen yard workers look for an ash tray in an engine room before putting out a cigarette. I have seen them lay canvas on turbine lagging before standing on it because the lagging was so clean.

KEEP UP YOUR MAINTENANCE

Too frequently, a ship will come in for overhaul and forget that some of the equipment is not scheduled for repair. The equipment sits. No one turns it over. No one operates it. Water or steam blow on electric motors. Dirt and dust bury other equipments. Three months later when the vessel prepares for sea trials, this equipment is energized. Motors burn out, bearings fail and emergency after emergency occurs. At this time in the overhaul. money is tight. One vessel came in from sea trials and had completely wiped every bearing on a forced draft blower. It resulted in a $5000 job one week before the completion date. No work had been done on the blower. No work had been done on the damper either. In fact, the zerk fittings on the damper had never been greased during the overhaul. The vessel operated the sister blower on the boiler, the damper stuck open and the blower under discussion was driven backwards by air from the sister blower. A shaft driven lube oil pump on the blower dutifully sucked the oil out of the bearings.

Another standard sea trial item is the vent blower. One almost invariably burns out, and it is usually a big one. The result is a last minute rewind job and a deck or hull opening.

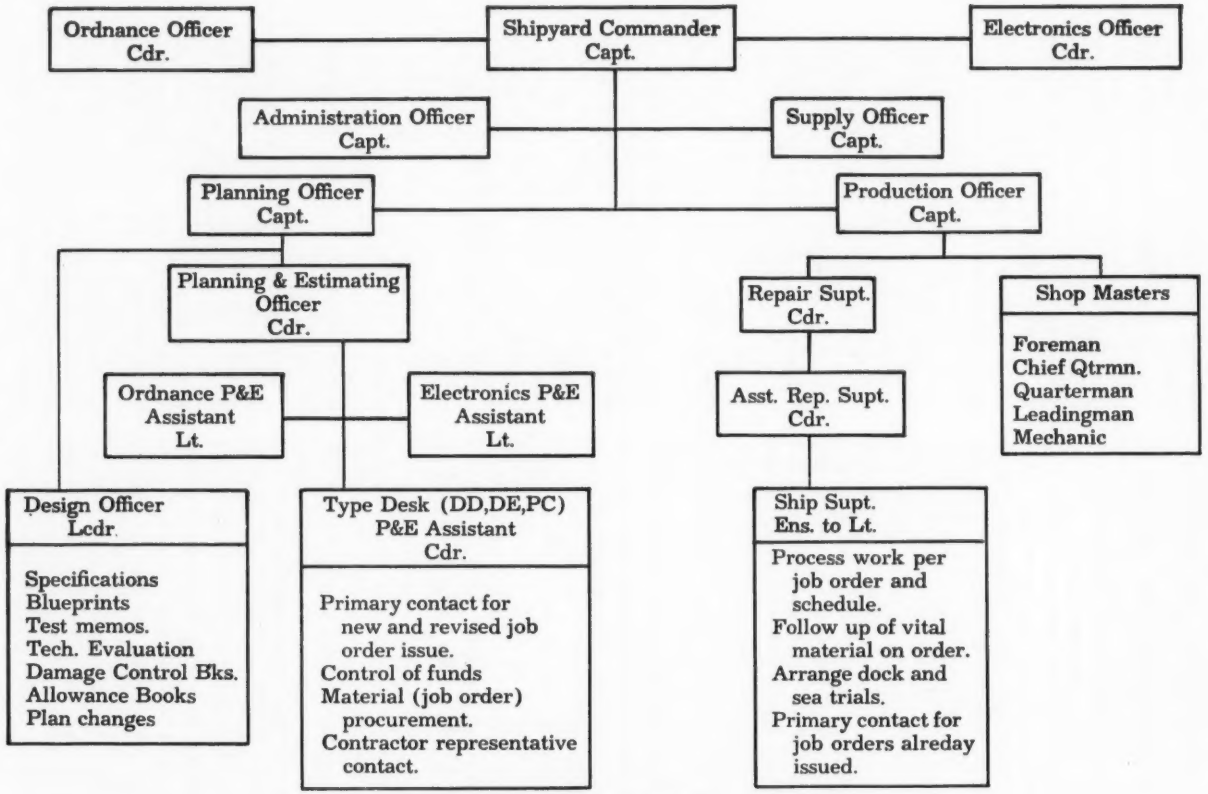
CHECK OUT YOUR EQUIPMENT

With the conclusion of your overhaul, demand time to properly operate and check out your equipment. Some people will hate you for being so particular, but everyone will be happier when you send a letter listing nothing but minor deficiencies after a thirty day period at sea. If you are not absolutely satisfied, say so. Do not be lulled by the fact that you may be planning to operate from the yard on RFS for a few days. The shipyard can not permit people to work on board during your Ready For Sea period. Either you are finished, or you are not finished; there is no in-between. It sounds like a tough rule, but it really works to the mutual benefit of all hands.

IN CONCLUSION

A good shipyard overhaul is an art. For many officers, the shipyard overhaul is their first experience of this type. The natural result, therefore, is that their overhaul period becomes a training period. If an officer can start the overhaul with a few good hard facts as a guide, he will be able to progress his job orders very nearly like a veteran.

Every problem has a solution, and a right solution at that. If we conscientiously seek it, regardless of whether the answer is a sweet or a bitter pill, you will wind up with a good overhaul, we will wind up with a better reputation and each of us will have gained.



VEST POCKET GUIDE TO YARD OVERHAUL

BOATMEN AND YOU AND ME

CAPTAIN VERNON E. DAY, U. S. COAST GUARD

THE AUTHOR

entered the Coast Guard from the State of Idaho and was graduated with honors from the U. S. Coast Guard Academy, class of 1927. He has served in various capacities aboard major types of Coast Guard vessels; as instructor, engineering subjects at the Academy; as Planning Officer, Coast Guard Yard; and as Chief, Engineering Divisions at New York and presently, Seattle. He has commanded the Cutters Tampa (renamed Saranac) and the Ingham.

His primary interests and the majority of his assignments have been in engineering. He has been most active in promoting safety within and without the service and is the author of several papers on this subject. He is a member of the Society of Naval Architects and Marine Engineers (currently vice-chairman of Pacific Northwest Section), The Society of American Military Engineers (currently President of the Seattle Post), this Society, and Tau Beta Pi, New York Epsilon.

Of his four children (three boys) the eldest is already a graduate mechanical engineer, and the youngest is headed engineering-wise. His principal hobbies are photography and carpentry, but he also dabbles in arts and crafts. His zest for living is reflected in all he does, and may be detected in this writing.

It has been amply demonstrated that helping boatmen to help themselves is far more effective than just standing by to rescue them when they get into trouble.

Calls for Coast Guard assistance have been increasing every year. Fortunately the number of lives lost has not only remained low, but is decreasing, and we are dedicated to keeping it that way. In fiscal 1953 we answered 591 calls which involved 2572 persons. We took credit for direct saving of 163 lives; we recorded only 13 lost. Since there are over 26,500 numbered small boats in the 13th Coast Guard District, and this does not include the host of rowboats and outboards, under 16 feet in length which are not required to be numbered, you can readily see that, statistics wise, boating is a pretty safe venture. And it ought to be, for in the past few years enormous pressures have been brought to bear for safety.

The list of individuals and the organizations which have made this contribution is long, almost too long for review here, much as I would like to give full credit for their fine accomplishments. Not only has there been technical progress but more important still is the educational aspect. Large commercial companies who are manu-

VEST POCKET GUIDE TO YARD OVERHAUL

facturers and suppliers of marine products, including fuels and oils, underwriters, and publishers, the several boating fraternities and the Government have supplied a continuing barrage of instructional material. If we had one copy each, of what has been distributed by the thousands, piled up on a table, it would make a very impressive stack. I'd hate to have to carry it very far. "Seek and ye shall find" never had a truer application. In fact, the boatman scarcely needs to seek, he cannot avoid being exposed to it. He has it thrust at him from all sides.

Yet, the safety record shows that something is still lacking, and that is the something I am going to write about.

We all acknowledge the need for safety. And we are in substantial agreement on many of the current measures being taken by industry, the boating fraternities, and the Government. We recognize that there is little new in the way of principles which can be offered. We grow a little bit tired of having it talked about all the time. We tend to wave safety missionaries aside with "Oh, I know all that. Everybody knows that; you aren't telling me anything new!"

All right, so we know all about safety. THEN WHY DON'T WE ACT AS IF WE DID? If we can answer this question, perhaps we can find some solutions.

We must examine man, since he, not his boats nor his gadgets, is primarily at fault. Let's consider a few of his shortcomings. Oh, this list could be stretched to great lengths, but let's take just a few: KNOW-IT-ALL; OVERCONFIDENCE; PROCRASTINATION; SELFISHNESS and THOUGHTLESSNESS; HURRY; THRILL; LACK OF PERSPECTIVE; and finally, THAT WE ARE THOROUGH BELIEVERS THAT STATISTICS DON'T APPLY, at least, not to us.

When faced with brand new situations we are all eager to try our wings. Boatmen, and you and me—we're no exceptions. "Learn by doing" they say, ah, yes, but experience is a dear, dear teacher. "I am the Captain of my ship; the master of my desitny" says the know-it-all yachtsman as he sees all that open water before him and feels the surge of power responding to his touch. The possession of a power boat encourages free lance attacks against the traditional enemies of the seaman—the water and the weather. He is possessed of power and of freedom, and no one is going to tell him what he should or shouldn't do. But there are those who try, who go all out to make things easier and more pleasant, and above all, safer. But what does he do? Well, here is what three young men did: Two of them bought a surplus Navy open lifeboat, 24 feet long, with a 25 H.P. inboard gasoline engine. They had no previous experience at sea, and so they invited a friend who had been in the Navy to go along with them. They sailed out of Rockaway Inlet and to the open sea, right by the big red storm warning flag. Like their confidence, their gas tank was full enough. The ups and downs soon used up the gas and there they were, drifting further and further at sea in a now strong off shore wind. When the men failed to reach their destination, their families spread the alarm, and the search was on. Coast Guard lookouts, four patrol boats and two planes combed the area, but the weather was bad and the visibility worse. They were not seen. But they were lucky! After spending a miserable, seasick afternoon and all night bailing and tossing, the weather moderated and along came the S. S. *Brigus*, which took them on board and their boat in tow. When they were interviewed, what do you think they said? We didn't know how much gas it would take? We didn't know those

flags were storm warnings? Yes, they said these, but more significantly they said, "There was no one to help us, not a boat in sight yesterday when we needed help, and today on the way in the ocean was covered with them." It never occurred to them why they were alone on the ocean; why, with the red bunting flying, those more experienced stayed in port. Nor did they ask. These apprentice boys in men's clothing needed no one to TELL them anything; not much!

While I was in command of the Cutter *Ingham* patrolling off Cape Hatteras, we received a relayed distress call from a supposed fishing vessel. It was snowing and blowing, really nasty winter weather. We had expected no particular difficulty in finding him as our radar ought to pick up a fishing vessel easily, but we cruised 30 miles south four miles off the beach, and then came back two miles off. Finally, there he was, not a fishing boat but a 26 ft. cabin cruiser, painted white, completely iced over, and all but lost among the whitecaps in the snowstorm.

The radar didn't find him—human eyes did—some 20 pairs! We finally got a line aboard him, and eased offshore for deeper water. I had asked the two men if we should take them aboard, but they were so exhausted and seasick they didn't want to make the exertion. But after tossing for an hour they begged to be taken off, and so we shortened the tow, brought the boat to the quarter, swinging one of our men down and hoisted them aboard with bowlines. They were practically helpless. I'll never forget the looks of gratitude on their faces as we half walked, half carried them to shelter! After they got thawed out and rested, we learned their story. The owner's friend was from inland and had never even seen the ocean before. He especially wanted to go fishing. The weather seemed favorable, so off they went. It wasn't long after they got well offshore that a winter storm came up. The boat could barely keep its head up, and finally, the engine was so wetted down it stopped, and couldn't be restarted. Fortunately, the battery operated radio worked, and he was able to call for help. They drifted all night until they could hear the roar of the breakers and then anchored. The regular anchor soon parted, the spare was put over—but with only a 21 thread line left, it too was almost chaffed through when we found him. There is no question but that we saved his boat from destruction, and two lives. He admitted that he knew better than to pit his little cockle shell against the North Atlantic in winter, but OVER-CONFIDENCE got the best of him.

"South of the border, down Mexico way" they have a perfect expression for one of man's worst anti-safety vices. Manaña. This means more than tomorrow. We call it procrastination. Our inner conscience tells us we ought to fix that leaking gas line, we know all about that safety rule which says that one gallon of gasoline has the same whoomp! as 80 pounds of dynamite. But it was only a weep at the union when we discovered it yesterday, and it's probably no worse today. Anyway, we aren't dressed to repair a gas line. Besides, we have the family on board, and if we stop to fix it we will be late arriving at our favorite cove for lunch, and everyone will be cross. We don't want to spoil our good time; we can get by, at least until tomorrow. Good old manaña! What a neat dodge! Solves all our problems. But wait a minute, does it? Well, not for the Yacht *Semar*. Two young men thought they could put it off. They wanted to show their mothers, who watched from shore, their speedy getaway, and who would want to disappoint his mother? At the first click of

the starter, WHOOMMB! and the yacht was a total loss. Fortunately, there was help near and the boys were rescued. No, manaña is not the answer. We must continually fight off this lethargy which would take possession of us. Granted that our lives move at such a pace none of us can do everything he sees the need to do. Therefore, we have to choose, and we should do first things first. The railroads go so far as to proclaim SAFETY FIRST, and you know, its not a bad idea for boatmen, too.

It isn't hard to find examples of selfishness. We can draw them from the records by the dozens. It's easier still for thoughtlessness. On 8 April 1949 the tanker *Cleveland* off the coast of South Carolina sighted a yacht making very heavy weather, came alongside, and seeing no one on deck blew repeated blasts on the whistle. No one appeared, and so the tanker radioed a description. This just fitted the yacht *Keewatin*. It was learned from the brother of the owner that she was then enroute from Nassau and could well be in the position reported. He also said that during rough weather it was his brother's custom to lock his two small children in the cabin, for safety's sake. Speculation immediately had it that the parents had been swept overboard, and the children were helplessly locked in, and with what privations, no one knew. Here was a human interest story which made coast to coast headlines, and shifted the rescue agencies into high gear. Word even reached Nassau about the affair, and the Parrots were amazed at their own obituaries. When the weather had turned for the worse, they had come back and snugged down, and all was well. That is, all was well except that everything that could float or fly in the vicinity was out searching for them. Meanwhile, the unknown yacht turned up safe and sound, too. The folks below decks were blissfully unconscious that their failure to answer the tanker's challenging whistle would set up such a commotion. Not all cases of thoughtlessness like these make the headlines, but we answer many needless calls each year looking for people who didn't think it necessary to keep others informed of their boating progress, or lack of it.

The Thrill of Speed is much worse than its cousin, Hurry, but both get yachtsmen into a peck of trouble. An inland yachtsman had his boat on a trailer, and in his hurry to be the first of his gang out to their boating site, turned out to be the last—in fact his boat never got there. Around a curve at 55 his trailer carromed off a big truck going the other way, broke loose and without benefit of champagne or even bilge water, launched his boat into the base of a cliff.

There is a place for speed, and we all thrill to it. On the highway, we should drive as if we had a boat in tow—for we have. And on the water we must stay away from bathing areas lest we repeat the leg chopping incident that happened on Lake Tahoe several years ago and sent the boat operator to jail for six months, gave him a $1500 fine and a whopping big liability settlement. Unfortunately not all the trouble was vented upon the guilty. Justice may have triumphed, but it couldn't replace that well recognized asset, the young woman's legs.

Scientific and manufacturing progress have multiplied the power available at the touch of a button, the push of a pedal, or the shift of a gear. It is multiplied alike for the wise and the foolish. Now I do not wish to imply that most motorboat operators are fools, for the record plainly shows otherwise. But the record also proves that a lot of them are foolish. I'm sure

you must have met one—but like the purple cow you'd rather see than be one. Foolishness is generally due to a lack of perspective—the inability to see wholes. The impulse of the moment is all too often the sole governing factor for our actions.

On the "Beautiful Ohio" last 4th of July a deckhand was talking to the skipper of a tug. "You know," he said, "a lot of people are going to lose their lives today in traffic accidents. We are lucky to be out here on the water where we are safe." Within a few minutes he was dead—drowned, and so were three others.

A young man and his wife and two children were crossing the river in an outboard, on their way to visit the grandparents, and spend a pleasant holiday. The father was operating the outboard, and turned to meet the tug's wake head-on, but somehow the boat rolled so as to pitch the mother and her son out. Instead of circling to come back alongside, the father, who was a fair swimmer, stopped the engine and dove in after them, leaving the little girl in the boat. The tugboat captain glanced backwards just as the man leaped into the water. He immediately backed his engine and turned to give assistance. The deck-hand came running out to see what all the commotion was about, and immediately started over the side. The captain shouted, "Get a life jacket first"; but the deck-hand ignored the warning. The captain then threw several life preservers, but none came within reach of those now struggling for their lives.

Man is not a fish, and when burdened by his clothing, he is not even a good imitator. The odds are all against him, and this fact is generally known, but while still out of the water, oh! how little is it appreciated! Four useless drownings! Why? Simply because there were no life preserves worn. There could have been—except that the outboard had none, and the deckhand chose to take to the water without one.

Is this catastrophe unique? By no means! Our files bulge with such case histories. Contrarily, the reports of drownings where life jackets have been worn are rare indeed. "The drowning man will grasp at a straw" says the old adage. Even out here in wheat country it isn't always available. How much better to provide something more substantial! Those of us who would carry our safety messages to Garcia must face up to the realization that people will not do even the simple things they know to be proper unless they fully appreciate the necessity, unless they gain PERSPECTIVE: the ability to see more of the whole picture.

This spring a $30,000 beauty was taken out of the storage yard and prepared for the summer season. The woodwork was cleaned, painted or varnished, and general repairs were made as seemed necessary. The finished job was something to be admired, and everything was in readiness for the family to come on board tomorrow. Did I say everything? Well, almost. There were some pinpoint rust spots showing on the outside of the gasoline tank. They didn't amount to much; no actual drips; just the moisture of gasoline. Besides, to get the tank out would require tearing into the wood, and messing things up, and worst of all now, delay. The boat was equipped with shore power connection to run the battery charger and the refrigerator, and as the latter was stocked up with good food and plenty of beer, the switch was thrown over, before leaving for the night. Where had he seen that item about statistics show that

gasoline fires were the most prevalent cause of motorboat accidents? Oh, well, what did it matter? He had fire extinguishers. It wouldn't happen to his boat. Famous last words! It happened about 5 the next morning. All that was left was a mass of splintered wood and some metal parts, now sunken alongside the dock. Scratch $30,000. Scratch the pleasant weekend so hopefully planned. Scratch the family's enthusiasm for boating. Scratch one more boating customer! If he was one who trusted in a rabbit's foot, he certainly overlooked what happened to the rabbit. Statistics have a way of catching up with rabbits *and* boatmen, yes with you and me!

Having cited some examples of man's faulty behavior, let's now see what remedies can be applied. KNOW-IT-ALL and OVERCONFIDENCE can be antidoted by more complete instruction and training—but it has to be skillfully done. PROCRASTINATION we can't do much about, except hope for the best. SELFISHNESS and THOUGHTLESSNESS we can definitely cure by substituting a moral code. HURRY and THRILL we can subdue as we build up PERSPECTIVE to see more of the whole picture from the initial action all the way through to the final outcome. And we can lessen the damage done by the belief that STATISTICS don't apply to us by reducing those statistics.

The examples I have provided and many more which you can supply out of your own experiences, show that the real culprit in this unsafety business is us—Boatmen, and you and me. That means *WE* must mend our ways.

To accomplish this requires education, the kind we call safety education, and more of it. The important thing is repetition; over and over again, like learning a language. Simple telling or reading is not enough. Psychologists have found out it takes 3 to 5 or more times before an idea really soaks in unless there is an overpowering event to emphasize it. You can remember from your youth, and can now see it in your children; you have to tell them over and over and sometimes have to give them a good smack. Now you can't go around smacking your fellow boatment with your hand, but there are other ways.

Let's go back to the man and his family in the outboard. When he bought his boat, the chances are life preservers were drawn to his attention. The same may have occurred when he bought the engine. Most dealers are pretty good about speaking up for safety, especially when there is a sale in the offing. And to try to clinch his sale, he probably pointed out that the law requires one life preserver for each occupant of any motorboat. Common sense would seem to indicate this as good practice, too. But the man had probably been in other boats where they were not used and this tended to negate the common sense observation. All told, the matter of life preservers probably came up directly only 3 or 4 times. Anyway, events *proved* his instruction was insufficient.

He probably had never seen a body drag. The Coast Guard uses a length of 1½ inch iron pipe, with large fish hooks, barbs removed spaced along its length. Its a mighty nasty looking piece of apparatus. In use it is dragged along the bottom, the idea being to hook into the flesh or clothing of the victim. Sometimes we don't find the body by this method. Our young man probably had never seen one which had come up after being in the water several days—or sometimes weeks. Have you ever seen a bloated, floating body? Its not very pretty, all bleached out white, and slimy. Frequently the cheeks, nose and fingers have been eaten off by crabs or fish. Your food doesn't taste right for days, and you always toss in

your sleep, or what passes for sleep, the first night afterwards. That's one first night performance I prefer to miss. If our young man had gone through just one such experience, he would have taken life preservers along. Likewise, the deck-hand would have donned one before going over the side. He would also have divested himself of his clothing had it been sufficiently impressed upon him that about the only thing clothing in the water is good for is to serve as a catch for a body drag. Yes, it was true, he was safe out there ON the water that 4th of July, but not IN it!

Now had the dealers, or the Power Squadron, or the Outboard Boating Club of America, or the Coast Guard Auxiliary, or better still, each of these salesmen-for-safety in turn, approached this new boat owner, EFFECTIVELY, life jackets and buoyant cushions would have been mentioned, yes, and they would also have been demonstrated; incidents where they saved lives would have been cited; and statistics, where for the want of their use, they didn't. They might have inquired if the man had children, and how would he face life knowing that his child had drowned because he stubbornly supplanted the better judgement of his elders with his own inexperiences? Supposing it was his wife, or, good swimmer or no, himself, what about the kids—his orphans? And they might have exhibited a body drag, that tool of the rescue agencies specially prepared for those who refuse to take flotation gear along.

Why is it that the same man who wouldn't think of going on a trip in his car without a spare tire, the absence of which would only delay him, will take out his boat without a life jacket and rush making the delay *absolutely permanent*? Oh yes, its easy enough to have 20-20 hindsight, although often, as in this case, it remains to be applied by others. Foresight is another matter. A man is technically blind if his vision is no better than 20-200, and that's about the foresight rating of our young man. He was safety blind. Would that someone, somewhere along the line might have found his prescription, and bettered his foresight! It has been said, there is no such thing as a dull subject; only dull teachers. Our boatman's stubborn resistance to lifesaving gear might have been broken had it been met with just a stubborn safety sales talk. Mr. Macy to the contrary notwithstanding, the customer is not always right. But, as business men know all too well, if they want to keep him as a customer for long, they have to be pretty diplomatic about how they pass the word. Its quite a challenge, isn't it?

Now if he sensed he wasn't getting anywhere in breaking through the iron curtain of indifference, our dealer might have called up a friend, say in the Outboard Boating Club or the Auxiliary, or he might even have called up a competitor and asked for help with his problem customer. This effective approach would have produced an eventual sale, and his drowned customer might still be on his active list today, not to mention his friends and relatives who are bound to be influenced away from boating by this much-too-close-to-home tragedy.

Yes, had these approaches been used, two fathers and one mother might still be leading useful lives, that is, if the cars didn't get them, and a young man would be growing up to take his place in our interesting world. One other observation: I'll bet the little girl, never again in her whole life, will get into a boat with no life preservers! And she's not being prissy or sissy about it either. She knows! She understands! She has gained perspective the hard and cruel way—it's permanent. Would that we might all be as sure as she is!

Several years ago my own daughter was learning to express herself with crayons. She had drawn a boat, sort of up-ended in the water, and I said, "Why, Dottie, your boat is sinking." She took her crayon and scribbled in the waterline higher and higher, and cried, "I know it, Whee, look at it go down!" I remonstrated "You wouldn't want to lose your pretty boat would you?" "Sure I would," she cried, as she crumpled up the paper and threw it high over her head with both hands. Her little face, set among black curls, was beaming with satisfaction. She was guarded, cared for and loved. All her little world was filled with a continuing flow of new things and experiences thrust upon her without effort on her part. She could not encompass the tragedy you and I would see in the sinking of a boat. Her boat didn't cost a million dollars, like the *Tony B*—the Seattle fishing boat which sank last month in the Caribbean. It would have taken a super salesman to have sold her on the merits of a boating safety program, but that's what we're up against!

Even as adults, most of us are not much different in our attitudes towards the other fellow's tragedy, because it doesn't touch us, or our experience. Its not our $1,000,000. We hear the newsboy shout: "Air crash kills 53; read about it!" and we do, because, like Dottie, we thrill to the excitement, and its not our problem. We say, "That's life." and let it go at that. Then tomorrow brings another headline, and yesterday's is forgotten. Will Rogers told us, "We are all ignorant, just ignorant about different things." If we are to be effective we must not remain ignorant about our safety. The missing information and ideas must be supplied in terms the other fellow can understand. And we must keep everlastingly at it.

It helps us in our attitude to have an experience of our own. I never thought much about broken bones until one day I was called upon to assist another officer who had taken a tumble. When he got to his feet, his right arm could only swing like a pendulum, and no wonder, for when we got his coat off and his shirt sleeve cut away, his arm bone was sticking out. I helped the Doctor set the bone, and stood by until the sewing up was nearly done. Then I went out like a light until some spirits of ammonia brought me around again. By that time the patient was all fixed up, but I had a whopping big lump on my head. Since then, when I hear of a compound fracture, I know what the term means. I can see the bone sticking out, the dripping blood, the white face, and I can even .... mm .... smell the ammonia, as things become real again. This has made me a more capable teacher. Without it I would more probably be letting someone else take up the cudgel for small boat safety.

Each of us must have a substantial moral safety code of his own. We must believe right down in our hearts that we have an obligation to society. It has been said of Government but its just as true of safety: "We protect our privileges by accepting our responsibilities." You cannot legislate people into safety any more than you can into any other standard of behavior, and please note: That's chiefly what safety is, a standard of behavior. A reckless driver has been defined as one who passes you in spite of all you can do. In all we do we must *set the example*. When should you say? "Do as I say and not as I do!"—NEVER! Example must follow precept or our voicing of the safety message is so much idle chatter —and don't think it won't be so recognized by others. Edgar A. Guest closes a gem he wrote with: "... And the lectures you deliver may be very wise and true, but I'd rather get my lesson by observing what you do! For I may misunderstand you and the high

advice you give, but there is no misunderstanding how you act and how you live!" A concomitant part of teaching is to set the example. Our youngsters, and many others, like Edgar Guest has so aptly described, will mostly follow the lead we take. Be sure its the right—the safe one! Its not enough to know what's right. The desire to do it must be close coupled! The acid test comes: When you know what's right, will you do it? And WILL YOU DO IT EVERY TIME?

From time to time I have given my four children instructions in the dangers of firearms, and have tried to combat the radio and comic strip's free use of violence. However, on my youngest son's ninth birthday, he was given a toy pistol, a very realistic one, holster and all. The table had just been cleared of the supper dishes, and we were in that pause which awaited the arrival of the birthday cake. All of a sudden he whipped out the pistol and drew a bead on me. I said, "Chip, you pointed that gun straight at my eye!" Quick as a flash he came back with: "I did not. You must have looked straight down the barrel!"

John Q. Public frequently finds himself looking straight down the barrel over which we, who are safety minded, sight. In our attempts to keep boating safe, whether it be as tradesmen, salesmen, underwriters, publishers, administrators, enforcement officer, counsellors, teachers, or just plain boatmen—you and me—it is necessary that we understand and respect the viewpoints of the other fellow. So much depends upon which end of the gun we are on!

Most of us are not close enough to small boat safety to take direct action, like the tug boat captain who threw in the life jackets as soon as he could, but like him, we can shout a warning, and in our official positions, we can shout it from the masthead. The fact that it will fall on mostly deaf or pre-occupied ears must not keep us from trying. Edmund Burke told us: "All that is necessary for the triumph of evil is that good men do nothing." Well, you and I *know* where we stand. Its not so much that we don't know these things but that we don't think about them enough to be effective, and if we meet head winds—are rebuffed—we may give up. There's no more need to give up in teaching than in sailing. You can make good progress against the wind, as you sailors know. You tack first one way and then another. If you luff you have only to swing around for a different psychological approach.

I haven't been very specific about small boat safety—what to do and what not to do. I haven't reviewed the existing nor proposed any new safety codes. All these things are well documented, and readily available in many forms. They have been prepared by experts and sponsored by substantial organizations. This is the place to get such information. Instead, I have talked about boatmen and you and me. I have really talked about a lot more than just boating. You will find 101 applications in your cars, offices, farms, and homes, but each require effort on your part, you good people!

You have all heard of the three E's of safety. Actually, there are seven: Effective Engineering; Effective Enforcement; and Effective Education. I've passed the first two double E's as being quite able to stand on their own, and have talked only about the third pair. I know I've used up a lot of your time, but let's take one last quick look at Effective Education. When you say: Now this equipment will promote safety; or, the law requires such and such procedure; we who are interested in your safety think this is a good idea; you really ought to do this—what appeal does this kind of talk have? ABSOLUTELY NONE! Its so

much water on a duck's back. This gentle rain of platitudes will not penetrate the average boatman's thick feathered coat of KNOW-IT-ALL, OVER-CONFIDENCE, PROCRASTINATION, HURRY, THOUGHTLESSNESS, or cure his LACK OF PERSPECTIVE or his belief that STATISTICS DON'T APPLY to him. Nor will it ever produce 20-20 foresight or even come near it. The chemical industry has produced a wetting agent so powerful a few drops in a tub of water will sink a duck. His protective oils are neutralized. That's what we need in our teaching methods. Unfortunately, such a wetting agent is not put up in handy packages, nor is it even easily recognized but it does exist. Its ingredients are: A little fanfare, a touch of color, something dramatic, something humorous, something personal, *repetition*, and sometimes, a little blood. Then all you have to do is get it on the duck, but how?

Say, did I leave one "E" out? So I did! Do you know what it is, this applicator? Its ENTHUSIASM! That's where you came in, and I bow out. May the enthusiasm which has bound us together keep boating safe—for boatmen and you and me!

CHARACTERISTICS OF TODAY'S FAMILY OF TURBOPROPS

ACKNOWLEDGEMENT

H. W. Campen, of General Electric Company, is the author of this article, which was published in the May, 1955, issue of *Aero Digest*.

Before designing an aircraft for turboprop power, the engineer must give consideration to the various turboprop configurations, and to the comparison of the turboprop with other power-plants in the spectrum. There are three basic configurations, the single shaft turboprop, the free turbine turboprop and the dual rotor turboprop.

The single shaft or so called fixed turbine turboprop is shown in schematic in Fig. 1. The compressor and all turbine stages are on the same shaft. This shaft drives the propeller through a reduction gear located forward of the compressor. Exhaust gas is ejected to the rear through a jet nozzle to obtain additional jet thrust, sometimes called residual jet thrust. The single shaft turboprop in the form of the G.E. axial flow T-31 became the first U.S. turboprop to fly. A timely example of this type machine is the Rolls Royce *Dart*, a centrifugal flow design, which powers the *Viscount* airliners.

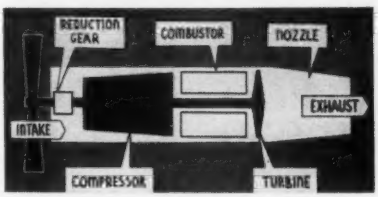


Figure 1. Single shaft turboprop.

The second basic configuration is the free turbine turboprop. For this powerplant, the power turbine, or turbine that drives the propeller, is not mechanically connected to the compressor turbine. A typical free turbine version has an internal power shaft as shown in Fig. 2. Note that the power is directly transmitted from the power turbine to the reduction gearing by an

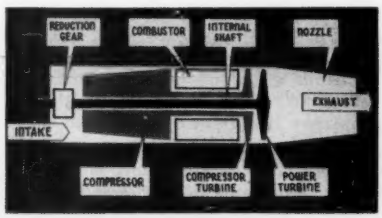


Figure 2. Free turbine turboprop, internal power shaft.

internal shaft. This shaft rotates inside the compressor, the hollow shaft that connects the compressor to the compressor turbine, and the compressor turbine.

This engine also uses a jet nozzle to get residual jet thrust. One of the first free-turbine turboprops developed was the Bristol *Proteus* which will power the Bristol *Britannia* airliner.

The third basic type is the dual rotor turboprop illustrated in Fig. 3. This turboprop has two separate compressors which are in series. The high pressure compressor is connected to the high pressure turbine by a hollow shaft. The low pressure or power turbine drives the low pressure compressor and supplies power to the propeller through the reduction gear. A jet nozzle is also on this engine.

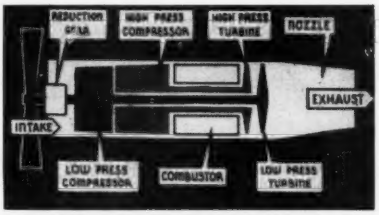


Figure 3. Dual rotor turboprop.

MODIFICATIONS

In addition to the three basic configurations many modifications can be used. For example, the single shaft turboprop may have its basic gas generator reversed as shown in Fig. 4. Air is drawn into the compressor at the rear of the engine. It flows forward through the compressor, combustor, and turbine set into a diffuser which is split around the reduction gear. Exhaust gases are ducted to the rear from the diffuser. A power shaft is extended forward from the turbine to connect with the reduction gear. Small turboprops of this type have been built for low speed aircraft; however ducting losses and inability to recover adequately ramming intake precludes this engine from operating efficiently at high flight speeds. Turbomeca of France has built the *Marcadau*, a turboprop based on this configuration.

Similarly, the free turbine turboprop may also have its basic gas generator reversed for low speed applications. This arrangement shown in Fig. 5 eliminates hollow and internal shafting, but at high air speeds it also suffers ram recovery and ducting losses. For each reversed gas generator configuration, the exhaust gases are ducted rearward to a jet nozzle. An example of this engine is the Continental T51-T-5.

It is also possible to pair any one of these turboprop configurations into a coupled unit to drive a propeller unit. For the coupled unit, two turboprops are placed adjacent to each other, each having a power shaft extension leading into a common reduction gear unit which drives the propeller. Bristol has coupled the *Proteus* to power the *Saro Princess* flying boat. Blackburn and Cirrus have coupled the Turbomeca-designed *Turmo*, which is a free turbine with a reversed gas generator; and Allison has coupled the T38, single-shaft turboprop, to form the T40.

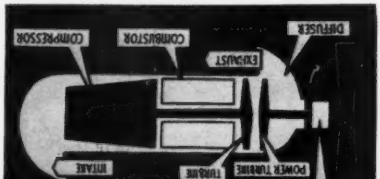


Figure 4. Single shaft turboprop with reversed gas generator.

DERATED TURBOPROPS

Another design concept of the turboprop which will receive a great deal of interest is the so-called derated turboprop. This machine accomplishes essentially the same thing as a supercharged reciprocating engine; that is, it maintains sea level power output at increased altitudes. For this reason, it is sometimes popularly called a supercharged turboprop. However, the derated turboprop maintains its power at altitude by a different means than the supercharged piston engine.

The supercharged piston engine maintains its sea level power output at altitude by compressing intake air in the supercharger. This supercharger compression increases the density of the air and thereby increases the mass flow of air into the cylinder which results in increased power output.

On the other hand, the derated turboprop maintains sea level output at altitude by increasing fuel flow. This increasing fuel flow increases engine operating temperatures. So that engine temperature will not exceed permissible values at altitude, engine temperature at sea level is decreased to allow the machine to maintain constant power with increasing altitude. Because its total available power is derated at sea level, this machine is aptly called the derated turboprop.

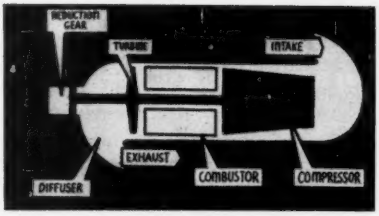


Figure 5. Free turbine turboprop with reversed gas generator.

To provide this additional capacity at altitude, the gas generator of the derated machine has increased size and weight over that required for its sea level operation. However, the reduction gear and propeller need not be increased in size for the derated engine.

This engine operates at low temperatures at take-off and climb power settings at the lower altitudes, because it is not delivering the maximum available power. Other engines at these conditions are operating close to their maximum temperatures. Also, the derated turboprop has reserve power at sea level to assure adequate take-off power for hot-day conditions.

Curtiss-Wright has advertised a derated turboprop which they have developed.

POWERPLANT COMPARISONS

Today's turboprops are attractive because they provide high power in relatively small and light weight packages. For example, turboprops are now flying that produce well over two ESHP for each pound of engine weight, whereas the best reciprocating engines deliver slightly better than one ESHP per pound of engine weight.

Piston engine size is limited to roughly 4000 SHP. Piston engines larger than this would present very difficult weight and control problems. Turboprops have already been demonstrated that yield over 2½ times the power of the largest aircraft piston engine.

Present day turboprop specific fuel consumptions are somewhat higher than those of reciprocating engines. However, the many advancements being made in turboprop design should

make turboprop and reciprocating engine SFC's more nearly equal. Three principal items determine turboprop SFC. They are:

1) compression ratio,

2) temperature ratio of ambient temperature to turbine temperature, and

3) compressor and turbine efficiencies.

SPECIFIC FUEL CONSUMPTION

Fig. 6 illustrates generally how turboprop SFC can be improved by increasing compression and temperature ratios. The compression ratio equals the ramming intake pressure rise times the mechanical compression. Notice that for a given temperature ratio, increasing compression ratio decreases SFC only to a certain amount; then further compression increases SFC. Also, for a given compression ratio, increasing turbine inlet temperature yields successive diminishing returns of improved SFC.

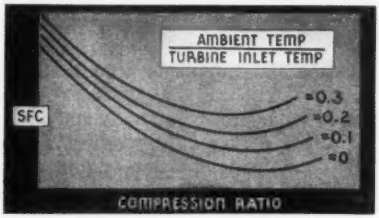


Figure 6. Turboprop SFC versus pressure and temperature ratios.

Turbine inlet temperatures are being increased because of advances in turbine metallurgy and turbine bucket cooling methods. Design improvements are raising compressor and turbine efficiencies and are permitting higher compression ratios without imposing excessive penalties of weight and mechanical complexity. One of the chief objectives of turboprop engineers is to improve SFC characteristics, and it is safe to predict that the engineers will have substantial success.

COMPRESSION RATIO

The turboprop has an inherent advantage over the reciprocating engine in that it shows a greater SFC improvement with increasing flight speeds than does the reciprocating engine. Because of the turboprop's basic intake design, it can efficiently convert the velocity of intake air to ram pressure rise. Thus, as flight speeds increase, the compression ratio increases resulting in an improved SFC as shown in Fig. 7. However, the reciprocating engine can not as efficiently convert the velocity of intake air to ram pressure rise because of the engine's intake friction losses.

On the minus side of the turboprop SFC ledger is this engine's SFC characteristics for part power settings. Fig. 8 illustrates percent SFC versus per-

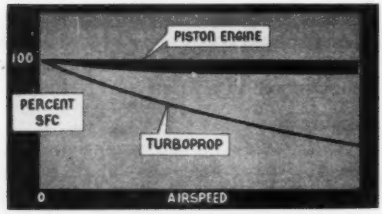


Figure 7. SFC versus airspeed.

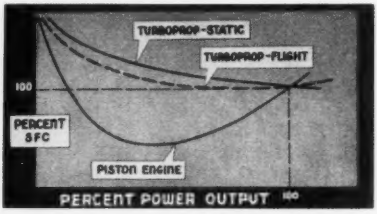


Figure 8. SFC versus power output.

cent take-off power for the reciprocating engine and for the turboprop. One-hundred percent SFC is assumed to occur at take-off power for each powerplant.

At static conditions turboprop SFC increases as power output decreases for the following reasons:

1) the compression ratio decreases,
2) the temperature ratio decreases, and
3) compressor and turbine efficiencies decrease when power falls below the design condition

However, at certain altitude and flight speeds, the turboprop curve may have a dip in SFC similar to the reciprocating engine curve. At maximum power the combined effect of the mechanical compression and the ram pressure rise creates a compression ratio that may be on the upturning part of the curve, Fig. 6. Altitude, of course, reduces the ambient to turbine temperature ratio. As power is decreased at a flight condition, the initial effect of reducing the compression ratio is to decrease SFC. Just as at static conditions, increases of temperature ratio and of design air flow and shaft speed tend to increase SFC. But the overall effect of altitude and flight speed is to flatten or put a dip in the SFC versus power curve.

Similarly, a turboprop with a high operating turbine temperature has a flatter SFC versus power curve than a turboprop operating at lower turbine temperature but having identical pressure ratios and component efficiencies. This condition results because the decrease of compression ratio has less undesirable effect at low temperature ratios than at high temperature ratios.

POWER VERSUS SHAFT RPM

An important characteristic of an aircraft powerplant is its power output compared to shaft speed. It is desirable for a given change in shaft speed to have a small change in power. This ideal facilitates smoothness and sensitivity of control and provides low propeller speeds and consequently low propeller noise at cruise power settings.

A single-shaft turboprop's power output decreases very rapidly with decreasing shaft speed as shown in Fig. 9. This condition is expected because the work to drive the compressor places a heavy load on the power shaft. The dual rotor turboprop does not lose power as rapidly with decreasing shaft speed because part of the compressor work load is separated from the power shaft. The free turbine turboprop loses very little power with reduction of shaft speed because all the compressor load is separated from the power shaft. The reciprocating engine loses less power with decreasing shaft speed than does the single shaft turboprop.

At flight conditions, the ram pressure rise reduces the effect of compressor load compared to power output. Therefore, for the various turboprops, changes in shaft speed causes less change in power output than at static conditions.

The turboprop can operate continuously at a higher percentage of take-off power output than the reciprocating engine. Cruising powers for a

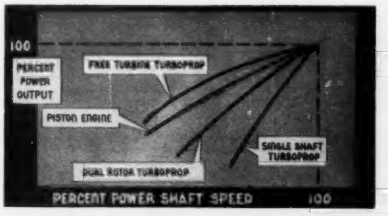


Figure 9. Power output versus shaft speed, static conditions.

turboprop can be in the vicinity of 90 percent take-off power whereas the cruising powers of piston engines are generally restricted to less than 65 to 75 percent take-off power. Reciprocating engines could be designed to operate continuously at higher part powers but only with serious weight penalties.

AMBIENT TEMPERATURE

The output of a turbine engine is more sensitive to ambient temperatures than piston engines. Fig. 10 indicates percent power change versus temperature change. The power output of a turbine engine is a function of the heat energy added which is determined by the compressor air discharge temperature and turbine inlet temperature. The turbine inlet temperature is fixed by metallurgical limitations, so the amount of heat energy that can be added depends on the compressor discharge temperature which changes as a function of ambient temperature. As ambient temperature decreases, compressor discharge temperature decreases allowing more heat energy to be added thereby creating an increased power output.

The same activity occurs in the piston engine. Again the output is a function of heat energy added which is determined by temperature after compression and temperature after combustion. Combustion temperature is limited so heat energy depends on temperature after compression which in turn depends on ambient temperature.

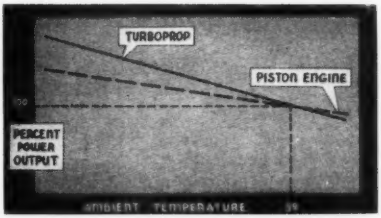


Figure 10. Power output versus ambient temperature.

The output of each powerplant varies with ambient temperature but the piston engine is less sensitive because it operates at much higher combustion temperatures; therefore, a change of temperature after compression caused by an ambient temperature change has less effect on the amount of heat energy that can be added.

TURBOPROP VERSUS TURBOJET PERFORMANCE

Before comparing performance of a turboprop to a turbojet the investigator must establish certain ground rules. Specific fuel consumption can not be used as a yardstick of comparison because

$$\text{Turbojet } SFC = \frac{\text{Net jet thrust}}{\text{Fuel flow}} = \frac{F_n}{W_f}$$

$$\text{Turboprop } SFC = \frac{\text{Equivalent Shaft horsepower}}{\text{Fuel flow}}$$

$$= \frac{ESHP}{W_f}$$

where equivalent shaft horsepower equals shaft horsepower plus the net residual jet thrust converted to horsepower.

These two SFC terms are completely different. The output term of the turbojet SFC expression is propulsive thrust whereas the output term of the turboprop SFC is primarily shaft energy which must be converted to propulsive thrust.

The total useful work of any aircraft powerplant is equal to the propulsive thrust times the aircraft velocity. A good measurement for comparing different powerplant types is overall thermal efficiency which may be expressed as:

$$N_{ot} = \frac{\text{Total useful work}}{\text{Fuel Energy}} = \frac{F_n V_p}{W_f H_f}$$

where,

N_{ot} = overall thermal efficiency,
V_p = aircraft velocity,
H_f = heating value of fuel.

Overall thermal efficiency may be considered to be made up of three basic efficiencies described as follows:

$$\textit{Engine thermal efficiency} = N_t = \frac{P}{W_f H_f}$$

where P=power either in the shaft form, or in the potential form of high pressure and high temperature gas.

Kinetic efficiency=nozzle efficiency, or propeller efficiency.

$$\textit{Kinetic efficiency} = N_k = \frac{\Delta KE}{P} = \frac{(W/2g)(V_r^2 - V_p^2)}{P}$$

where ΔKE=change of kinetic energy,
W = mass flow,
V_r = relative (to aircraft) discharge velocity of either jet or propeller exhaust,

$$\textit{Propulsive efficiency} = N_p = \frac{F_n V_p}{\Delta KE}.$$

Overall thermal efficiency equals the product of these three efficiencies. An examination of propulsive efficiency shows the advantage of the turboprop. Now,

$$N_p = \frac{F_n V_p}{\Delta KE}$$

and

$$F_n = \frac{W(V_r - V_p)}{g}$$

$$\Delta KE = (W/2g)(V_r^2 - V_p^2)$$

therefore, after substitution and simplification,

$$N_p = \frac{2}{1 + (V_r/V_p)}$$

OVERALL THERMAL EFFICIENCY

It is seen that propulsive efficiency is highest when the relative discharge approaches the aircraft velocity. At slow flight speeds the turboprop's propulsive efficiency is higher than the turbojet's because propeller discharge velocities are less than jet nozzle discharge velocities. If discharge velocity is reduced for a turbojet, it results in a decrease of pressure ratio and/or turbine temperature either of which results in a decrease of engine thermal efficiency. Fig. 11 demonstrates the change of overall thermal efficiency of a turboprop and a turbojet versus flight speed. As flight speed increases, engine thermal efficiency increases for both machines. Nozzle efficiency remains fairly constant for the turbojet but propeller efficiency declines especially at high subsonic airspeeds. Propulsive efficiencies increase for each engine, with the turbojet propulsive efficiency approaching that of the turboprop at high airspeed. Fig. 11 indicates an overall thermal efficiency advantage

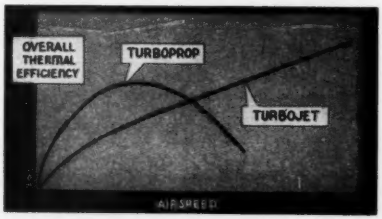


Figure 11. Overall thermal efficiency versus airspeed.

for the turboprop at low flight speeds and a disadvantage at high flight speeds. The cross-over point cannot be rigidly defined because variations of engine and propeller efficiencies can change its location appreciably.

Overall thermal efficiency alone does not present the entire comparative story. The turboprop adds weight in the form of additional turbine stages, reduction gear and propeller to achieve the overall thermal efficiency superiority at low flight speeds. This extra weight penalizes the turboprop aircraft's short range performance compared to a turbojet aircraft's. Fig. 12 shows the realms of application superiority for each engine. For short ranges the turboprop, because of its weight penalty, can not compete with the turbojet unless low speeds are desired. As range increases the turboprop gains superiority for higher speed applications because the disadvantage of its weight is outweighed by its overall thermal efficiency advantage. The turboprop's application area includes

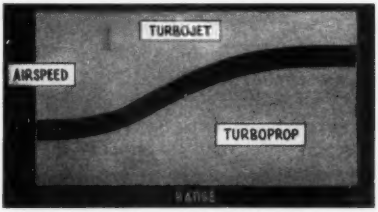


Figure 12. Areas of application superiority.

greater airspeed with increased range until the airspeed is reached where the overall thermal efficiency is greater for the turbojet than for the turboprop.

In general, the rate of power decrease with increased altitude is slightly greater for a turboprop than for a turbojet. Each engine loses available power from the basic gas generator as the air mass flow through the machine diminishes with increased altitude. In addition to this power loss, the turboprop suffers the additional loss of reduced propeller efficiency with increased altitude.

JET EXHAUST

An exhaust nozzle is utilized on a turboprop not only to discharge exhaust gas but also to improve performance at flight speeds. Fig. 13 shows overall thermal efficiency versus percent of energy expanded through jet nozzle for curves of constant airspeed. At static conditions maximum overall thermal efficiency occurs when nearly all available energy is transmitted to propeller. As airspeed increases, overall thermal efficiency can be increased by converting part of the available energy to thrust by a jet nozzle. If the jet exhaust velocity is equal to the propeller discharge velocity, the propulsive efficiency of the jet kinetic energy and the propeller kinetic energy are equal. The kinetic efficiency of converting potential gas energy to kinetic energy is greater than that of converting shaft energy to kinetic energy by the propeller. Therefore, the overall thermal efficiency is increased. The amount of energy expanded through the jet nozzle depends on the magnitude of flight speed for which the turboprop is designed. A secondary advantage, that of reducing reduction gear and propeller weight, results from utilizing a propulsion nozzle.

In the future, the turbofan engine may displace the turboprop on some high speed applications. However, the turboprop is expected to maintain its position in the powerplant spectrum as the engine undergoes continuous development.

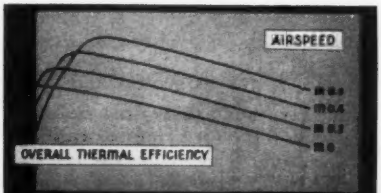


Figure 13. Energy split between propeller and jet nozzle.

A STANDARDIZATION STUDY

"Action without study is fatal. Study without action is futile."—M. Beard

ELLSWORTH F. SEAMAN

THE AUTHOR

Articles by Mr. Seaman have appeared in the ASNE Journal over a period of years, starting with the November 1934 issue. The present article reflects some portion of the author's standardization experience that had its beginning in 1931 in the Bureau of Engineering.

Mr. Seaman is a Registered Pofessional Engineer, Head of the Standardization and Conservation Planning Branch of the Bureau of Ships, Chairman of two committees and one sub-committee in the International Electrotechnical Commission and one of the four United States members of a task group concerned with Pan American standardization.

PREFACE

Writing a specification is not the only standardization responsibility in the procurement of a satisfactory product. The area that lies beyond the preparation of a purchase specification needs to be explored. Is the delivered product actually the item defined by the specification? If this is not the case, how is the product identified as to degree of difference? If a specification product actually reaches the usage stage, is it used or misused? How do you reflect the answers to these questions in a constantly improving specification cycle? These problems and the relationship among them form the theme for this article.

INTRODUCTION

The practical usefulness of standards and specifications is one measure of the effectiveness of standardization effort. A full examination of a specification requires study that begins with procurement of a product. It extends through the phases of inspection, shipment, stocking and eventual application in service. Each of these phases should be evaluated to determine whether the specification is adequate for the need. A review of the study conclusions, not individually but with a bird's eye viewpoint, can materially contribute to a well-balanced standardization program.

PROCUREMENT

The use of a specification for procurement is the first test of practicability. The supply potential is immediately indicated by the bids received. If inadequate interest is shown on the part of producers, it may indicate that the specifications are unrealistic. Products requiring variations in standard production line techniques may have been specified. This means added expense to the consumer. It may also increase the manufacturer's cost out of proportion to profit that is realized. All of this points to the need for more thorough coordination with industry during specification development. It furthermore emphasizes the importance of confining specification requirements to essential needs. On the other hand, requirements over and above standard production practice sometimes exist and must then be specified. Screening such requirements as to validity is the best insurance for adequate availability. The elimination of non-essential requirements should make the producer sympathetic to cases where the need is important.

Deviations are defined here as those variations from specifications which are permitted at the time a contract is in the making. They are danger signs in several ways: They could mean unrealistic specification requirements; they may also represent agreement to departure from apparently minor requirements which in service turn out to be major. If this occurs, the performance of the product is no longer an indication of specification suitability. Service performance reports on these products do not indicate need, or lack of need, for specification revision. It is therefore important, in judging the adequacy of a specification from service reports, to eliminate chance for false conclusions drawn from performance of items not conforming to specification requirements. This same reasoning holds true for all departures from the specification, regardless of nature, when a product is considered on the basis of its service performance. This point is further developed in that part of the discussion dealing with other kinds of specification variations.

Figure 1 illustrates the relationship of the procurement phase of specification usage to the specification cycle as a whole. It graphically points up the fact that certain types of actions should result in specification revision. The needed revisions resulting from repeated or major deviations are not always easy to develop. When these deviations occur as a part of extensive procurement activity in a large organization, the problem is one of finding a simple and automatic procedure for collecting pertinent papers and analyzing their significance.

INSPECTION

An accurate measure of whether a product conforms to specification requirements is the function of inspection when lots are offered for delivery under the contract. In order to truly check product quality against requirements, inspection must be strict but fair. Unspecified things cannot be required and known departures from specifications can be permitted only through the conscious act of waiving requirements. Waivers, by definition here, may represent the same kind of specification departures as occur under deviations. A different term is used only to identify the action as to its sequence in the specification cycle. Waivers of a major or repetitive char-

Figure 1

- - - - Possible Revision Indicated

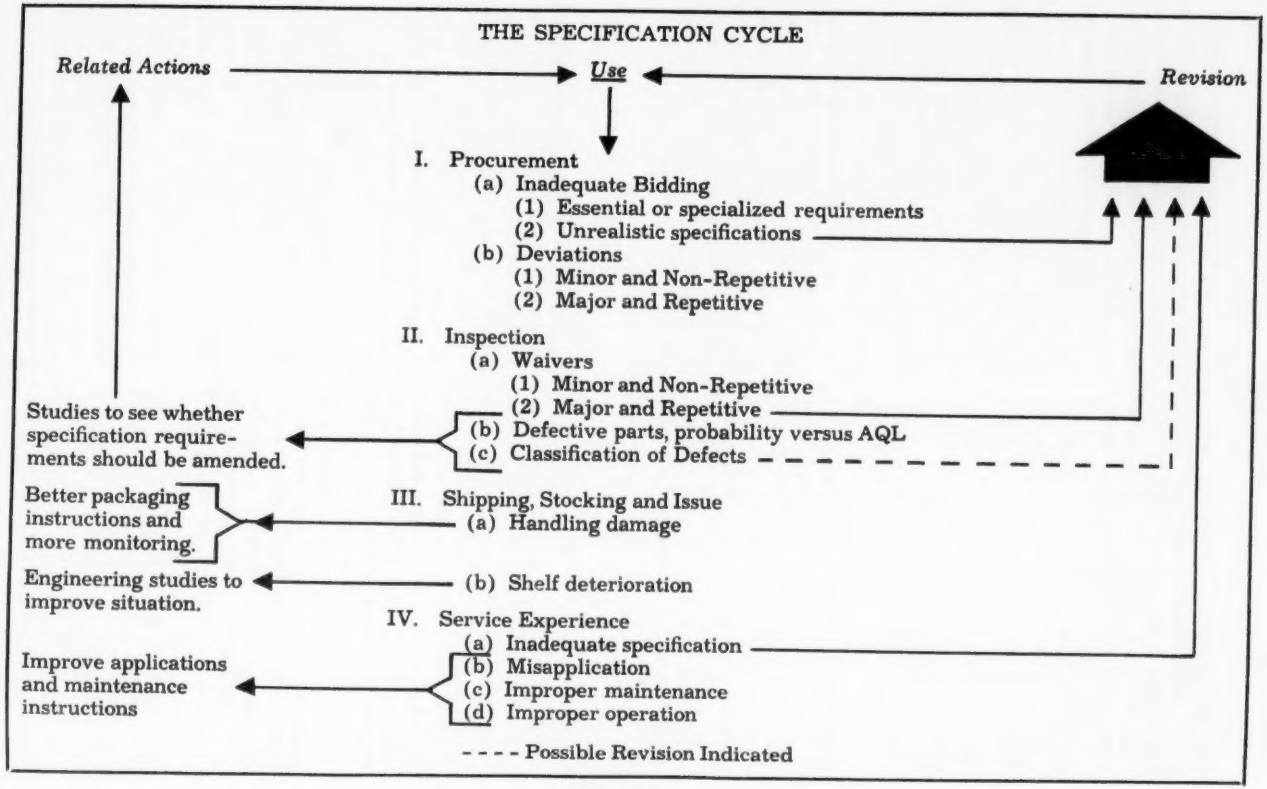

THE SPECIFICATION CYCLE
Related Actions
Use
Revision
I. Procurement
(a) Inadequate Bidding
(1) Essential or specialized requirements
(2) Unrealistic specifications
(b) Deviations
(1) Minor and Non-Repetitive
(2) Major and Repetitive
II. Inspection
(a) Waivers
(1) Minor and Non-Repetitive
(2) Major and Repetitive
(b) Defective parts, probability versus AQL
(c) Classification of Defects
Studies to see whether specification requirements should be amended.
Better packaging instructions and more monitoring.
III. Shipping, Stocking and Issue
(a) Handling damage
(b) Shelf deterioration
Engineering studies to improve situation.
IV. Service Experience
(a) Inadequate specification
(b) Misapplication
(c) Improper maintenance
(d) Improper operation
Improve applications and maintenance instructions
- - - - Possible Revision Indicated

Figure 1

acter should normally lead to specification revision.

It is an accepted and useful procedure under what is now known as quality control, to inspect production lots on the random sampling basis. Thus the degree of risk you are willing to assume will determine the sample size or number of items inspected under contract. Sampling tables are available* for reference purposes and are specified as applicable in contract inspection work.

It is a mathematical certainty that some non-specification products will find their way into stock regardless of whether one hundred percent inspection is attempted, or whether a sampling table is used. The number of such cases will be small, but when they occur the performance of the product in service is not a measure of specification suitability.

A far more important and technically difficult problem is that faced by the Inspector in determining whether a defect is major or minor in borderline cases. A very good or very bad inspection sample presents no problem. It is a case of clearcut acceptance or rejection. Guide lines for classifying defects represent specification interpretations. They are an important part of the definition of the kind of a product that is placed in service and hence have an important bearing on service performance. It is therefore necessary to consider the meaning of the guides as they may affect service performance. Continued engineering study in this field will do much toward developing realistic specifications that improve in the direction of clear-cut interpretation.

SHIPPING, STOCKING AND ISSUE

During the process of shipping, stocking and issue of a product, a proper amount of care in handling will prevent damage. Proper control is exercised through adequate packaging specifications and thorough handling instructions effective at points under control of the purchaser.

Environmental conditions to which a product is exposed during shipment can significantly affect the quality of a prodouct before it is placed in service. It is therefore important that the purchase specifications take this into consideration when it is practical and important enough to do so. Studies have been conducted in this field and the environmental transportation conditions insofar as they can be expressed are specified in MIL-STD-210. It may not be practical to attempt coverage of severe transportation conditions in the basic specification of a product. There would be no justification for certain special shipping requirements when they apply to a limited number of cases. It is therefore indicated that proper "boiler plate" requirements should be made a part of the procurement document, if and when applicable.

Shelf deterioration of a product while in stock can seriously affect the quality of a product. A determination of the level of quality at time of issue could be important to the service application. Studies of shelf life of dry batteries is currently underway. It would be helpful if similar studies were made on other products susceptible of relatively rapid deterioration while in stock. This problem is present for certain electronic components, paints and miscellaneous other items.

An interesting approach to this

* Military Standard, MIL-STD-105A.

problem has been developed by Dr. J. Greenwood in his "LIFO" versus "FIFO" discussion.* The symbols signify respectively, "Last in first out" and "First in first out." A good case is made in favor of the former procedure, both from the standpoint of economy and reliability. Greater reliability or endurance in service means here that a larger percentage of the life goes into usage rather than being wasted on the shelf.

SERVICE EXPERIENCE

After having traversed all other steps in the specification cycle, there remains one final test of the specification product, and that is its use in service. It is here that the most important contributions should occur in the direction of specification revision and improvement. If the product at this stage is really the one defined by the specification, then its performance will guide further specification development. The implication is inherent that an adequate service reporting system exists and that the pertinent information is channeled to that office responsible for the product specification.

If a product fails or is found inadequate in service, then the reason therefore must be determined as the result of an accurate analysis. Trouble caused by misapplication, improper operation or deficient maintenance are not corrected through the product specification. These problems fall within the scope of instruction books, service manuals, maintenance instructions or such other forms of literature as applicable.

CONCLUSIONS

a. When an item is procured in strict accordance with a specification, the nameplate where pertinent should identify the applicable specification by number and date. This will assist in having service reports that truly reflect the adequacy of the specification from the user standpoint.

b. Conversely to (a), variations from the specification should be identified with the product where they have been permitted. An auxiliary nameplate, where appropriate, might serve the purpose. Service reports on these products should develop patterns for better control over departures from specifications.

c. A well-integrated system of service reporting should be maintained. This means that specification revision is performed in a realistic way and is directly related to service performance.

d. Shelf life criteria should be developed for all items susceptible to appreciable shelf life deterioration.

e. Packaging and related problems should not be considered peculiar to the specification for a certain product, but should be channeled to the packaging experts who are best fitted to cope either with routine or special problems.

f. All factors affecting the performance of a specification product and not correctable in the specification itself, should be appropriately covered by manuals, instruction books, reference guides or other appropriate type of document.

* Department of the Navy, Bureau of Aeronautics, Quality Control Division Report—Issue Priority: Last in first out (LIFO) vs. First in first out (FIFO) as a method of issuing items from supply storage.

SUMMARY

The preparation of a standard or specification to cover an item is only the beginning of standardization. These documents define the terms of reference for procurement, inspection, packaging for shipment and performance. If initial requirements are found to be inadequate as the result of experience, then the document should be amended. The flow of specification usage experience is reflected in steadily improving specifications. A constant awareness of the parts making up the specification cycle (figure 1) serves to unite, in a realistic way, the documentation with a suitable end product.

MARINE APPLICATION OF AIRCRAFT PROPULSION SYSTEMS

U. A. POURNARAS

THE AUTHOR

was born in Athens, Greece, received the degree of the Bachelor of Science in Naval Architecture and Marine Engineering from the Massachusetts Institute of Technology. He has been associated with the design offices of John G. Alden, and Hickman Sea-Sled Co., both of Boston, Mass., and is presently employed as a Naval Architect in the Hydromechanics Laboratory of the David W. Taylor Model Basin, USN, where he is associated with the Hydrofoil Research Program.

SCOPE

The use of aircraft propulsion systems to propel marine craft has been attempted as early as 1919, when Dr. Alexander Graham Bell propelled the "Hydrodrome," an experimental craft sustained underway by the dynamic action of "water-wings," with two 350-bhp aircraft engines driving two 4-bladed air screws. Ever since, many a designer and hopeful backyard inventor have attempted to incorporate some of the desirable features of aircraft engines and propellers such as light weight and shallow draft, into their designs. However, as a rule, the finished products met with defeat in terms of both inefficient and uneconomic operation. The reliability and performance of the installations proved questionable, and left much to be desired before an aircraft-type drive could be seriously considered for marine application. Today, however, when the demand for higher operational speeds is continuously increasing, and improvements in weights and efficiencies assume greater importance, the problems involved in the marine application of aircraft propulsion systems must be reconsidered, and all possibilities fully evaluated.

In principle at least, we distinguish the following four possible combinations of powering agents:

1. Marine engines driving marine propellers,
2. Marine engines driving aircraft propellers,
3. Aircraft engines driving marine propellers,
4. Aircraft engines driving aircraft propellers.

The straight marine drive is of everyday experience with the naval architect and the marine engineer and is not dealt with here; the second type, a marine engine driving an aircraft propeller, has no apparent merits to warrant further consideration; aircraft engines employed to drive marine propellers offer desirable possibilities; however, we shall limit the discussion to the performance qualities and limitations of the aircraft engine in association with an aircraft propeller, the straight aircraft-type drive.

PRELIMINARY CONSIDERATIONS

The Powering Process

All marine vehicles depend upon the availability of power to maintain a steady state of performance. The performance analysis and the comparison of a number of powering-propulsion systems can be best arrived at through the consideration of the basic elements involved. The powering process, in the marine sense, is essentially one of energy transformation. The heat energy content of the "fuel" and the "oxidizer" is transformed into mechanical power within a "heat engine," and thence, the mechanical power output of the engine is transformed into propelling thrust through the agency of a propelling device such as a propeller. In deciding the merits of various propulsive arrangements, the efficiencies of each of the energy transformation steps should be carefully analyzed and evaluated, and the effect of each upon the performance of the vehicle investigated. We consider, then, the efficiencies of the various steps briefly, recalling the basic definition of efficiency to be the ratio of output to input.

a. *Thermal Efficiency:*

$$\eta_t = \frac{\text{mechanical energy produced in the system}}{\text{heat energy of fuel and oxidizer}}$$

The thermal efficiency as defined above will have a bearing on the fuel consumption and, therefore, considering the specific weight and heat content of the fuel, it will affect the speed, range and power characteristics of a vehicle. A useful engineering formula for the thermal efficiency is derived from the basic expression

$$\eta_t = \frac{(\text{shp}) \times (550) \times (3600)}{W_f H J} \approx \frac{.138}{c}$$

where W_f is the weight of fuel consumed per hour, H the heat value of the fuel approximately 18,500 btu/lb, and J the conversion factor, 778 ft-lbs/btu. The symbol c of the simplified expression is the specific fuel consumption in lbs/shp/hr. The thermal efficiency has a tendency to increase with higher compression ratios for the internal combustion engine, but the type of fuel used, a quality that denotes heat content, rate and degree of combustion, generally governs the permissible compression ratio, considering the detonation characteristics of the fuel.

b. *Propulsive Efficiency:*

$$\eta_p = \frac{\text{propulsive work performed}}{\text{mechanical energy produced in the system}}$$

From the definition above it becomes clear that the propulsive efficiency cannot be adequately defined unless the output and input of the expression are given a strict qualitative meaning. The energy input, the mechanical energy produced in the engine system, is usually measured at the driving end of the engine, and depending on the type of machinery and arrangement,

is called brake-horsepower, or shaft-horsepower. Power values so determined do not reflect the magnitude of internal system losses and other expenditures required for the normal operation of the engine. The effect is then evident in the magnitude of the thermal efficiency. Such procedure cannot be considered satisfactory, for it would deprive us of the analytical means of a step-by-step evaluation. Let us consider, for example, the cooling of a reciprocating, internal combustion engine. The cooling requirements of the engine can be calculated and the required cooling work established. Cooling, now, can be effected through the agency of a system of scoops, pumps, or both. The effect of the scoops is, of course, an increase in the resistance of the vehicle while the pump, if driven by a drive ahead of the point where shp or bhp is measured, consumes power that is not registered and is not entered into the computation of the propulsive efficiency, as defined previously. To penalize the thermal efficiency would not be strictly correct, and to consider the efficiency of the cooling arrangement independently of the propulsive qualities of a given arrangement would only complicate a comparison by introducing numerous variables, and render it meaningless. In other words, by adding the drag of the scoops to the resistance of the bare hull, we cause an artificial increase of the propulsive efficiency. Also, if the power required by the pumps is not included in the expression for the input, the effect is in the same direction, which is true even if the power expenditure is included in both the input and output expressions. To pursue this matter any further in deciding the proper place in the energy transformation steps of the powering process for such power expenditures, would only lead to long academic discussions. However, we may state that the proper analysis of a system, and the success of any attempt to improve its performance depend largely upon our ability to isolate and evaluate each of the steps involved in the process. We can summarize by stating that the propulsive efficiencies of two different arrangements can be used as a basis of comparison only when they are arrived at on common terms.

c. *Over-all Efficiency:*

The over-all efficiency is the product of the thermal and propulsive efficiencies and, therefore, self-explanatory.

$$\eta_{oa} = \eta_t \times \eta_p$$

Performance Considerations

The efficiency of a propulsion arrangement employing a propeller will depend upon the following:

a. Free-stream propeller characteristics, and those for the propeller as installed.

b. Efficiency of the powering component of the arrangement, alone and in association with the propeller.

a. *Propeller Performance:*

The free-stream propeller efficiency, in other words the efficiency of a propeller operating free of foreign body interference, depends clearly on the operating conditions such as the speed of advance, rotational speed, and power and thrust loads. The interference effects depend to a large extent on the geometry of the arrangement of which the propeller is part, and that of the bodies in the vicinity of the propeller. Such effects cannot be treated as a general case because even small modications of a given arrangement may in some cases result in large improvements, or penalties. However, with the aid of published experimental data and theory the designer can guide the design of an arrangement in such a way as to avoid unfavorable clearances and shapes, so that any adverse interfer-

ence effects may be kept to a possible minimum. Interference bodies that may be expected in shipboard applications of aircraft propellers are engine nacelles, supporting structures, decks etc.

b. *Engine Performance:*

The efficiency of the powering component of an arrangement, by itself, or in association with an aircraft propeller, will depend largely on the efficiency at which the auxiliary functions of the system are performed. These functions we call auxiliary in the sense that they do not contribute directly towards the propulsion of the craft, but are essential to the proper functioning of the engines. An outstanding example is the cooling of the aircraft engines.

Airplane engines are, as a rule, enclosed in cowlings. The purpose of the cowlings is two-fold. First, they must provide an engine enclosure of minimum resistance; second, they must act as a pump for the cooling air and pump it through the engine, or radiator. These two functions are distinctly different just as the amount of work required to be done on the cooling air is distinctly different from the ordinary aerodynamic drag of the cowling alone. An understanding of the air-cooling process is important to explain propeller performance, so that the magnitude and the nature of the power expenditures involved can be appreciated.

In order to cool an engine, a given quantity Q of air must be forced through the engine across a pressure drop $\triangle p$ per unit time. An increament in drag, $(D - D_o)$, is then observed. The cooling work done is $Q \times \triangle p$, and the work expended exclusively to cooling is $(D - D_o)\ V$. The efficiency of the cowling acting as a pump is,

$$\eta_{pu} = \frac{Q \times \Delta_p}{(D - D_o)\ V}$$

and the total drag,

$$D = \frac{Q \times \Delta_p}{V \times \eta_{pu}} + D_o$$

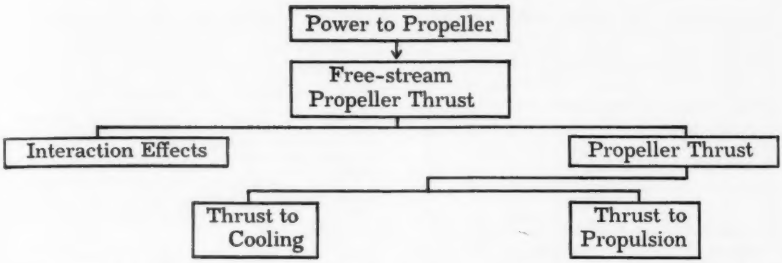
Another expression for the "pump" efficiency on the basis of experimental values, which is useful in visualizing the effect of cooling on the propeller, is

$$\eta_{pu} = \frac{Q \times \Delta_p}{(\eta_o - \eta_a)} \times \frac{1}{P}$$

where η_o denotes the efficiency of the propeller in front of a tightly closed cowling, i.e. with no cooling work performed, and η_a is the "net efficiency" of the propeller operating in front of an engine which is enclosed in a cowling suitably open for cooling work to be performed, and P is the power delivered to the propeller.

We see that, disregarding body interference, there is no real difference between a free-stream propeller and the same propeller operating in front of an air-cooled engine. However, the amount of thrust available to propulsion is not the same in the two cases, for the propeller operating under identical "conditions." The difference is the drag increment related to the air-cooling of the engine. The propeller thrust required to overcome this drag increase is not available to propulsion of the craft directly, but is essential to the smooth operation and life of the engine. The chart opposite indicates the propeller thrust expenditures.

The magnitude of "thrust to cooling" will depend on the efficiency of the cooling process, in which case both the absolute speed of advance and the pumping qualities of the cowling-nacelle-nose design are important. At relatively low speeds, say up to 100 knots, the contribution of the propeller to cooling may be expected to be considerable, especially when the propeller is designed for high speed operation.



Having now discussed the working details of an aircraft-type propulsion arrangement and its important elements in a broad sense, we consider next the performance of the aircraft propeller in more specific terms.

PERFORMANCE EVALUATION

a. *Propeller Performance:*

A systematic investigation aimed at the evaluation of different propeller-nacelle-cowling arrangements in regard to the cooling of aircraft radial engines, by Theodorsen and others at the N.A.C.A., brought about some interesting results. Six different, 3-bladed, 10-ft diameter, controllable pitch propellers of leading commercial and naval manufacture were used during these tests, in association with a number of nacelle-cowling-skirt-nose combinations, all of the same diameter, 52-inches, and the same length. The arrangement of the tests was such that the thrust measurements obtained corresponded to the net thrust of the propeller, after cooling and aerodynamic drag deductions. The thrust thus obtained represents the thrust available to propulsion exclusive of engine appendages. The test results were evaluated partially by plotting the net efficiency against the unit disk-power-load coefficient, P_c. The definitions are:

$$\text{Net Efficiency, } \eta_n = \frac{R\,V}{P}$$

$$\text{and } P_c = \frac{P}{q\,S\,V}$$

where

R=thrust available to propulsion
V=speed of advance
P=power delivered to propeller
q=dynamic pressure $\frac{1}{2}\rho SV^2$
S=propeller disk area, $\frac{1}{4}\pi D^2$
D=propeller diameter
ρ=density (air at sea level)

The value of R, then, is identical to the drag of a hypothetical craft, composed of the hydrodynamic and aerodynamic drag of the craft and its appendages such as the engine cowling. As P_c is inversely proportional to the cube of the speed, the results were plotted expressing P_c actually in the form of the inverse of its cube root, $1/\sqrt[3]{P_c}$. It must also be noted that the velocity increase and the contraction of the slip-stream of the propeller are proportional to P_c, which of course means that for equal values of P_c the stream flow will be geometrically similar for similar propellers and nacelle units, so that their efficiencies will be the same, provided that both propellers considered are operating at identical conditions. Model prediction is then possible on this basis.

An examination of the curves of the net efficiency vs. the inverse cube root of the unit power load coefficient for the six propellers tested shows that they are plotting within a narrow band, thus permitting the assumption that a single curve may be drawn to represent the performance of any of the propellers tested, and therefore, within

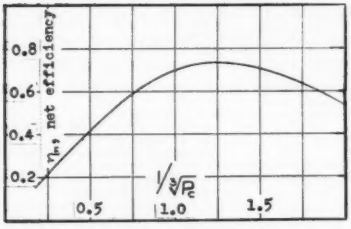


Fig. 1. Average "net efficiency" of 3-bladed, 10-ft. diameter aircraft propellers.

reasonable approximation the performance of an average 3-bladed, 10-ft propeller. Such curve is shown in Figure 1. It must be noted that the spread of the band which the curve is meant to approximate is actually wider at values of $1/\sqrt[3]{P_c}$ exceeding about 1.5 or so. However, the speed and power conditions corresponding to these values are not practical for marine application. On this basis then, we may proceed calculating the performance of an average, typical 3-bladed, 10-ft propeller. The results of these calculations are shown in Figure 2. Figure 2, shows the thrust available to propulsion plotted against power delivered to a typical 10-ft propeller, at a number of even speeds in knots. The thrust values are obtained from the simple relation

$$T = R = \frac{\eta_n P}{V}$$

where the net efficiency, η_n, is read from figure 1, at the value of $1/\sqrt[3]{P_c}$ corresponding to the speed V, and power P.

Inspection of Figures 1 and 2, shows that:

1. Small thrust requirements can be met with proportionally less power delivered to the propeller than larger thrust requirements. For

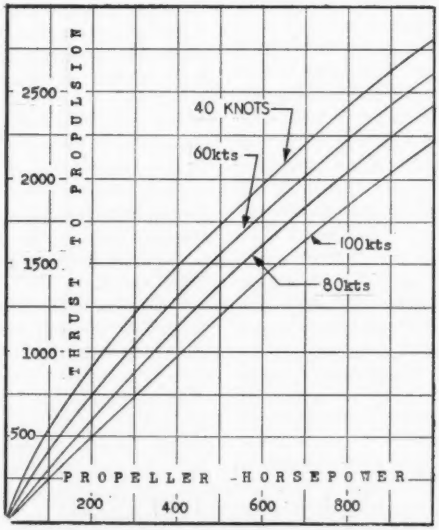


Fig. 2. Average performance of 3-bladed, 10-ft. dia. aircraft propellers.

example, if we were to propel a hypothetical craft of 1000 lbs of total drag at 60 kts, an engine delivering about 280-bhp to the propeller would be required, while a craft of 2000 lbs of total drag would require 700-hp delivered to the propeller to drive it at the same speed. In both cases, the same propeller is considered.

2. Smaller bhp outputs, and therefore smaller engines, appear to be more efficient at all speed up to 100 kts considered here.
3. The improvement in the net efficiency by decreasing power required decreases with increasing speeds.
4. It follows that a multiple engine installation is to be preferred over a single engine installation, from efficiency considerations.

b. *Model Prediction:*

The data presented in Figures 1 and 2, can be used to predict the performance of other propellers, of different diameters, geometrically similar to those represented in the figures. Differences in the relative dimensions of the cowling-nacelle units and the propellers have little effect on the performance, and can be accounted for by exercising reasonable judgement. The method of predicting optimum propeller performance is based on the significance of the power unit load coefficient, P_c, of which equal values correspond to equal propeller efficiencies when the similar propellers are operated at identical conditions, for example equal coefficients of advance,

$$J = \frac{V}{nd}.$$

To facilitate model prediction, Figure 3 is given showing the relationship among the propeller diameter D, power P, and speed of advance V. The two curves shown are derived from the following relationship:

$$P_c = \frac{P}{q S V} = \frac{P}{(0.5\rho).785 D^2 V^3} = \frac{k P}{D^2 V^3}$$

for operation at sea-level and standard density of the air. If, then, a propeller is to operate at the same value of P_c, and therefore efficiency, we have at once

$$P_{c\,10} = P_{c\,x}$$

and

$$\frac{P_{10}}{D^2_{10} V^3_{10}} = \frac{P_x}{D^2_x V^3_x}$$

where the subscripts 10 and x denote the propeller diameter.

At the same speed of advance we will have

$$(D_{10}/D_x) = (P_{10}/P_x)^{1/2}$$

and at the same propeller power

$$(D_{10}/D_x) = (V_x/V_{10})^{3/2}$$

The relation of RPM, N, speed V, and diameter D, is, for $J_{10} = J_x$,

$$\text{at } V_x = V_{10} \quad \frac{N_{10}}{N_x} = \frac{D_x}{D_{10}}$$

$$\text{and at } P_x = P_{10} \quad \frac{N_{10}}{N_x} = \left(\frac{V_x}{V_{10}}\right) 1/2 = \left(\frac{D_{10}}{D_x}\right)^{\frac{1}{2}}$$

In applying the above relationships one must remember that the curve of Figure 1, net efficiency vs. $1/\sqrt[3]{P_c}$, is a representative average curve for 10-ft, 3-bladed propellers, and is actually an envelope curve of optimum operating conditions for each of the propellers. Figure 1, can be used to arrive at general preliminary characteristics. The method of analysis, however, can be employed to predict propulsion characteristics when a propeller's characteristics are known, and the operating conditions expressed in terms of P_c, J and pitch are decided upon.

c. *Aircraft Engines:*

We consider next some of the characteristics of aircraft power plants that are considered as major advan-

tages by the proponents of their application for sea-borne vehicles. Namely, the specific weight and fuel consumption.

The fuel consumption, we have already seen, appears to depend on the compression ratio. Other factors, however, such as engine speed, torque, and therefore manifold pressure, also have important effect. Optimum thermal efficiencies of reciprocating internal combustion engines are of the order of 0.30, and the average fuel consumption at best is 0.45 to 0.55 lbs/bhp/hr. A typical fuel consumption chart is shown in Figure 7.

The weight of the aircraft engine is, of course, light, as it is to be expected of a high speed, light duty engine. Reported figures of 1.0 lb/bhp, or even less, are familiar. No matter how useful these figures are to the aircraft designer who is concerned with the performance of his design in both the take-off and flight conditions, a reconsideration of machinery weights is in order if the engines are to be installed aboard ship and compared with their straight marine counterparts.

During take-off, an airplane must reach its take-off speed within a minimum time and distance travelled. The accelerating force, the difference of the instanteneous drag of the plane from the propeller thrust, must then be fairly high. At the same time, the weight of the airplane determines the take-off speed, in consideration with the aerodynamic design, a fact that is easily appreciated in terms of the lift

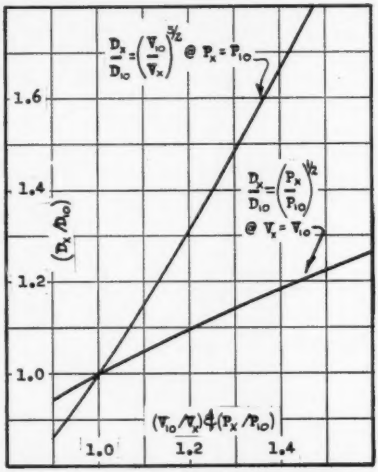


Fig. 3. Prediction of aircraft propeller performance from data of a typical 3-bladed, 10-ft. dia. propeller.

equation,

$$\text{Weight} = L = \tfrac{1}{2} P C_L S V^2$$

and its form

$$V = \sqrt{\frac{2W}{P C_L S}}$$

The aircraft designer, then, is very much interested in obtaining a maximum value of thrust at the lowest possible weight for a short period of time to accomplish take-off and climb. Consequently, aircraft engine manufacturers report the specific weights of their engines in terms of the maximum take-off power available. The take-off rating is higher than the continuous rating. Engine power ratings are also frequently reported to denote conditions other than short-time maximum. Such ratings include:

For Military:
Take-off
Emergency Cruising
Maximum Cruising
Continuous Cruising,

and for Commercial
Take-off
Emergency
Normal.

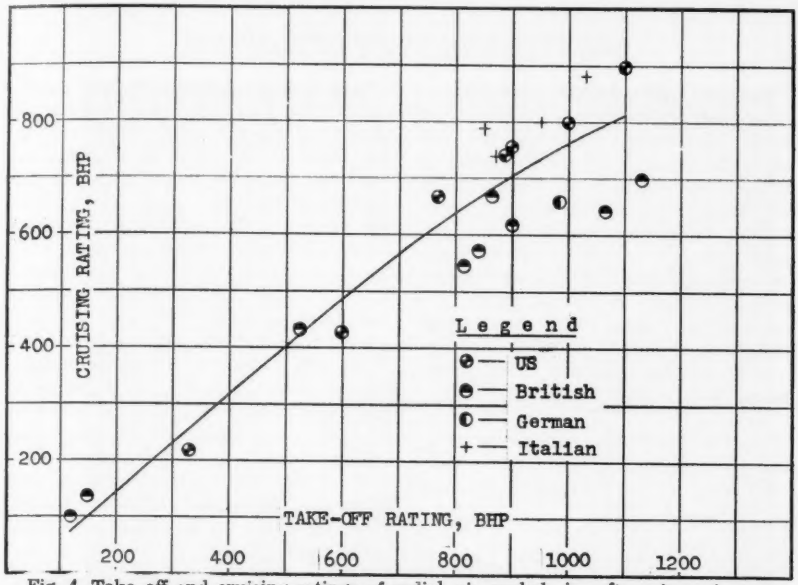


Fig. 4. Take-off and cruising ratings of radial, air-cooled aircraft engines. Average international practice.

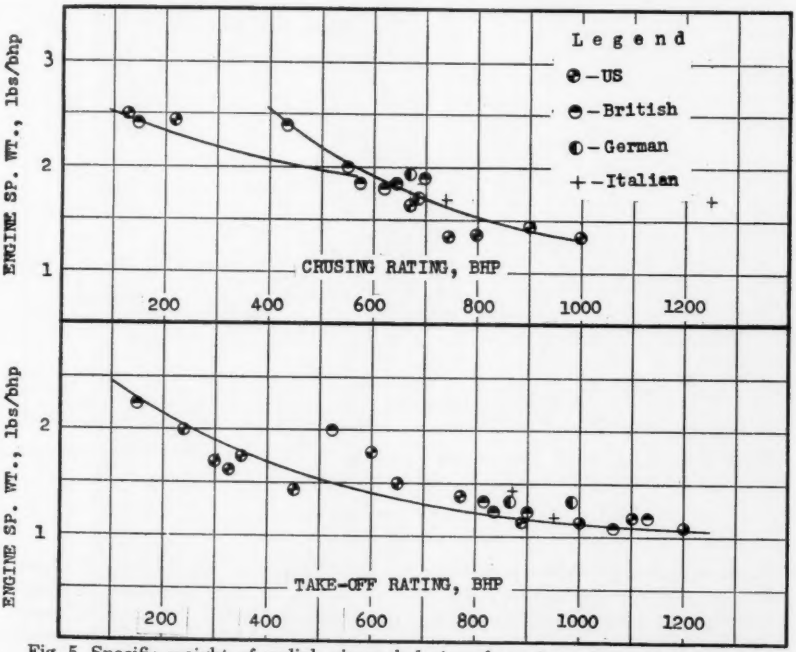


Fig. 5. Specific weight of radial, air-cooled aircraft engines. Average international practice.

These ratings reflect engine endurance and economy of operation in terms of power, engine speed and manifold pressure. If the engines are to be used to propel marine craft, the continuous cruising rating of the engine is of interest, and therefore, engine specific weights must be considered in terms of the continuous power output. Operation above the continuous rating will cause high maintenance costs, damage, and frequently complete failure of the power plants, if practiced for long periods.

Figures 4 and 5 are of interest. Figure 4, shows the relation of the take-off rating to the continuous cruising rating of a number of engines, up to about 1250-bhp maximum. Figure 5, shows the specific weights, lbs/bhp, on the basis of the maximum rating, in part (a), and the cruising rating, in part (b). The engines are of US, British, German and Italian manufacture, all are radial air-cooled, except for one 4-cyl. in-line at 150-bhp maximum. Curves suggesting the trend of weights and ratings are also indicated. All engines are of the 1944 vintage, most of them still available, or in production. To acquaint the reader with the performance of aircraft engines, Figures 6 and 7, are presented showing the speed-manifold pressure-power relation of a typical aircraft engine, the Pratt and Whitney R-1340-AN-2, and the fuel rates for another engine of much higher output.

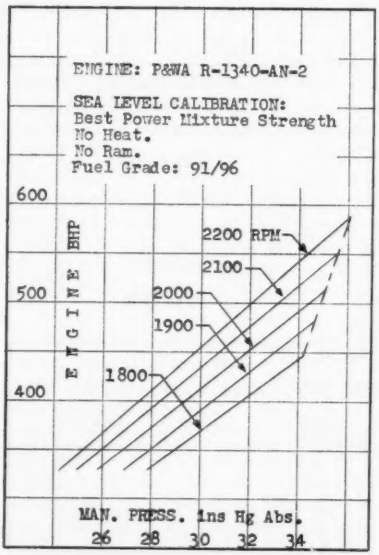


Fig. 6. Typical aircraft engine performance. (by permission)

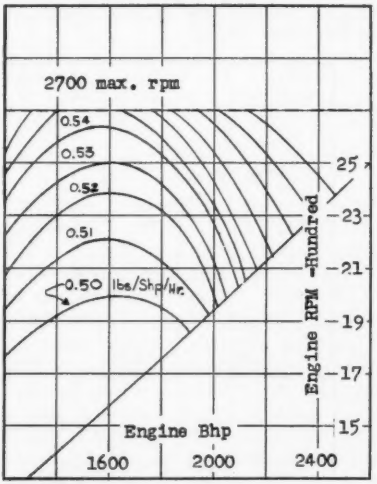


Fig. 7. Typical aircraft engine sp. fuel consumption.

CONCLUSIONS

Present and Future

Existing aircraft-type propulsion units can be successfully applied to marine craft under the following general conditions.

1. Absolute speeds of advance must be fairly high to insure satisfactory advance conditions, in association with practical propeller

The XCH-4, an experimental hydrofoil craft built recently by Carl for the ONR, USN, is powered with two 450-bhp aircraft engines capable of driving the craft at speeds in excess of 75 mph. (Official Navy Photo)

rotational speeds and diameters.

2. Whereas multiple engine installations appear more efficient than single installations, the maximum number of engine-propeller units that may be installed aboard a craft is limited, and consequently, the application of aircraft-type propulsion systems is probably limited to low-drag, light-weight craft.

3. Engine and propeller weights are relatively low, but values reported from the aircraft industry must be adjusted for continuous operation for the purpose of performance analysis and comparison.

The limitations of the existing aircraft propulsion systems for marine application summarized above, can probably become less severe in the future. Until successful cavitating marine propellers become a reality, the air screw offers a partial solution, at least, to the higher marine speeds. Marine requirements of relatively slow speeds, high loads, and long operating periods can be met to some extent if the components of a proposed air-propulsion arrangement are designed specifically for such application, instead of being selected from the light-duty products of the aircraft industry. It is also true that the financial cost of research and limited manufacture in this specialized field will probably affect a development adversely. However, as the slower speed aircraft types, such as the heavy patrol-bomber and others, assume a more leading role in the defensive efforts of our country, new developments towards heavier duty engines are in sight. Diesel aircraft engines have been used in the past, and new design and production techniques will probably re-introduce a suitable power plant into the aircraft industry. Other types of power plants such as the turbo-compound, the gas turbine, and others also offer possible answers to the marine problem.

Air-propulsion systems offer certain advantages for marine craft other than weight and draft. A properly balanced engine-propeller design is capable of producing high accelerating forces, the difference of propeller thrust and the resistance of a craft, especially at the low speeds of advance, thus contributing to the sustainment of a speed in a sea-way. Air propellers offer a divorce solution to the problem of floating debris, a quite serious problem in high speed marine craft. Adverse problems are equally involved. Corrosion, spray effect on thrust underway, vibration of cantilever-like engine supports, danger to operating personnel or restriction of deck working area, are all serious problems but not insurmountable. Some can be solved, others must be tolerated. It is the opinion of the author that in a good many cases, the advantages of air-propulsion will overcome the imposed restrictions at a profitable rate, and even costly research and experimentation will eventually be justified. At this time we become constantly more and more aware of the dynamics of high speed vehicles operating at, or near the surface of the water, and we can no longer ignore or fail to investigate any favorable possibilities. From the times of the "Hydrodrome" to the recent experimental examples we face the same problems; some we have overcome, others must still wait. Is it not always a matter of time?

THE RAM-JET—A PRACTICAL POWER PLANT

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THE AUTHOR

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The dawn of a new era casts a long light across the horizon of man's advancement in the field of propulsion. This time the light is cast in the shape of a ram-jet. (Figure 1).

The ram-jet, commonly referred to in guided missile terminology as the flying stovepipe, is a high speed rate of change device, propelled by the expulsion of heated gases. Today the ram-jet stands on the threshold of wide application in both piloted aircraft and guided missiles. Its ease of manufacture, simplicity, economy and performance dictate that its usefulness will be high and its demand widespread in aircraft and guided missile propulsion applications in the decade ahead. It can be produced quickly and cheaply with

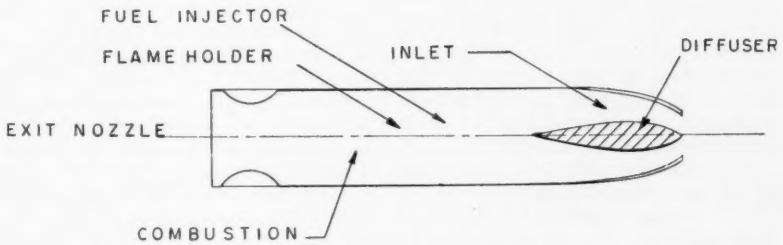

Figure 1

a minimum of tooling and does not require the tremendous engine laboratories and shops associated with many of the other forms of propulsion plants.

The principal underlying the operation of the ram-jet has been known for many years. A French engineer, Rene Lorin, is credited with the first application of the principal in a propulsive device. He first patented and published his idea in 1913. Other inventors have patented similar devices. In 1928 Fonó patented a similar idea in Hungary and Leduc in France in 1933.

The ram-jet was first successfully flown in this country in mid 1945. Work on the ram-jet was begun in 1945 in this country by the Bureau of Ordnance U. S. Navy employing a group of university and industrial organizations under research and development contracts with the Applied Physics Laboratory, The Johns Hopkins University acting as the central university laboratory. The ram-jet first made its public debut on 9 June 1946 when the Navy revealed the development by the APL/JHU and twenty (20) associate industrial and university groups of a supersonic engine weighing only seventy (70) pounds developing over 2000 horsepower and capable of speeds well into the supersonic region. Practical efficiency of the ram-jet is attained only at high speeds. Its development awaited the advent of high speed applicat'on. The world of supersonic speed opened vistas to the development and usefulness of the ram-jet as a practical device.

The ram-jet differs from all other propulsive devices in that it has no moving parts except for fuel regulation and control. Further it obtains the oxygen from the atmosphere through which it passes for the combustion process. The oxygen is burned with a hydrocarbon fuel. This offers a great advantage over rockets which must carry their own oxygen, greatly increasing space and weight lifting requirements. Conversely stated, the

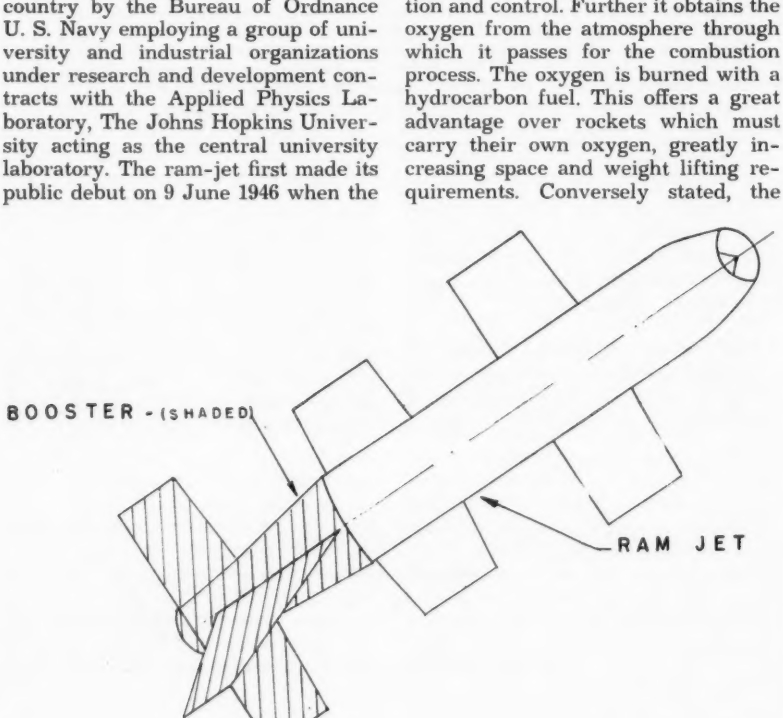

Figure 2

ram-jet can be constructed smaller and lighter and carry a larger "pay load" or explosive charge. For example, the German V-2 rocket carried 5½ tons of liquid oxygen and 4 tons of fuel. Had it been powered by a ram-jet the fuel oxygen load could have been replaced by explosives thereby increasing its lethality or replaced by more fuel to give it longer range.

Like most everything else in life, the ram-jet is not perfect nor is it without certain disadvantages. The primary disadvantage of the ram-jet is that it has to be moving at a high rate of speed before it will operate. To attain this speed it is necessary that a means be provided to give the ram-jet the required initial high velocity. This is presently accomplished by auxiliary rockets or "booster rockets" as they are commonly called. The ram-jet is attached to the forward portion of the "booster rocket" for launching. (Figure 2).

The booster rocket provides a tremendous forward thrust which accelerates the ram-jet to a velocity exceeding the speed of sound (speed of sound approximately 760 miles per hour at sea level) in several seconds. Once the aero-dynamic drag of the booster exceeds its forward thrust, it separates from the ram-jet and then the ram-jet takes over and accelerates under its own power.

The operation of this engine weighing less than one-half ounce to a horsepower (approximately one pound to a horsepower for a conventional engine) and having no moving parts is of extreme interest. The "flying stovepipe" takes air in through its forward opening and supplies this air to the combustion region of the ram-jet providing both oxygen, essential to combustion and mass to be driven from the exhaust. The air taken in is sufficient to produce thrust when expelled and the process of combustion is necessary only as a source of heating. The ram-jet is interested in the rate of BTU release only and if it were possible to produce heat in the jet without combustion the combustion process would be unnecessary. The ram-jet, in addition to enjoying a highly favorable thrust-to-weight ratio, provides peak performance at supersonic speeds. It also has a low specific fuel consumption, does not require costly alloys and uses ordinary hydrocarbon fuels, which add to a long list of desirable features of the ram-jet.

The operation of the ram-jet is in theory simplicity in itself. However, before examining the actual operation of a ram-jet, it appears appropriate to "dust off" some classroom physics in order that its operation may be more readily understood. Today, tomorrow and as far as we can see into the future, our every day life will make use of such established modern day terms as subsonic, sonic, supersonic, hypersonic, sonic barrier, thermal barrier, shock waves, the speed of sound, Mach number, Reynolds number, and many others. These are all terms associated with the phenomena experienced when objects move through the air at speeds from less than that of sound to speeds faster than that of sound (in the medium being considered). The layman is often confused by certain of these terms in that they have dual meanings. An example of this is found in the words sonic, subsonic, supersonic, hypersonic. In one meaning sonic applies to sound phenomena and the auditory ranges of the human ear and in a second meaning it concerns the phenomena resultant when a fluid flows or an object moves through a fluid. For the purposes of a study of the ram-jet we are concerned with the latter meaning as generally considered in the field of physics, namely a form of pressure gradient or variation moving through some material medium.

This disturbance is normally referred to as a wave. The elasticity of the medium determines the speed with which the wave moves through it. In the case of air where the pressure changes are small and rapid the square of the speed of sound varies directly as the ratio of pressure to density. Temperature affects the speed of sound and similar pressure waves in air at the rate of approximately two feet per second for each degree Centigrade change. Examples of this may be seen. The speed of sound in 86° F air is approximately 777 miles per hour (1140 feet per second). The speed of sound in 95° F air is approximately 784 miles per hour (1150 feet per second). The speed of sound in 77° F air is about 1130 feet per second or approximately 770 miles per hour. These figures consider normal conditions where pressure changes are quite small and do not consider high-intensity pressure variations such as explosions.

Now if we go back to our earlier statement that sound is a form of pressure variation which moves through some material medium we can recall that the train whistle causes windows to vibrate and the sound given off by an airplane moving at a high rate of speed causes buildings to shudder as will the notes from a pipe organ cause the walls and windows of buildings to vibrate.

If we fire an object so that it moves through air with a speed less than the pressure wave speed (subsonic speed) —the pressure waves proceed the object. (Figure 3). For simplicity in presentation, let us take as an example a set of conditions where a cannon ball is expelled from the barrel of a cannon at a speed less than that of sound. Let us now examine Figure 3. Here we see the cannon ball moving through the air at a speed less than that of sound. It is preceded by the sound waves it has generated. The cannon ball moving at a sub-sonic speed will not overtake the sound waves.

However, let us now turn our attention to this same cannon ball fired at, let us say, the speed of sound. Here we find the most difficult case. The speed of the cannon ball is equal to the speed of the pressure waves (sonic speed). These pressure waves converge to form a "wall" in front of the cannon ball. Now let us study Figure 4. Here we see what is commonly known as the "sonic barrier" where all the waves ahead of the cannon ball have combined into a single "wall" or "barrier." This shock wave is a very strong force made up of the combination of the smaller forces

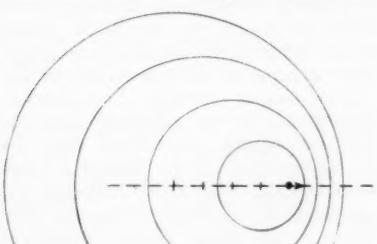

Figure 3

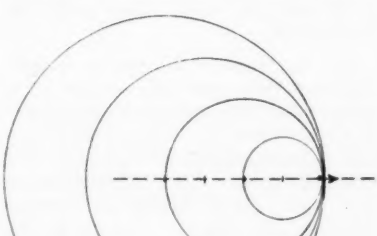

Figure 4

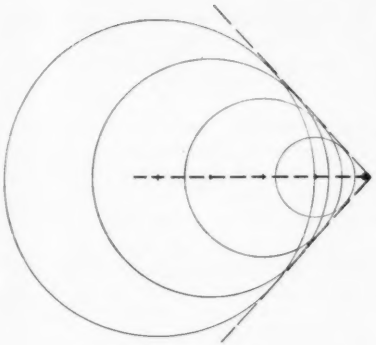

Figure 5

which have converged. From this figure it may be understood why it is desirable to use a type of propulsion other than propellers to reach the supersonic regions. It may further be understood why it is necessary to go quickly from subsonic to supersonic in order to break through the wall or barrier which is found. This is commonly referred to as the "sonic barrier."

Now if we fire the cannon ball a third time and this time—to a speed greater than the pressure wave speed (supersonic speed)—a new set of conditions is found. (Figure 5). Here we find the situation more difficult to show in diagram. We see in Figure 5 the cannon ball preceding the shock waves where a conical region of compression proceeds its path. Here we find pressure waves converging ahead of the cannon ball and along the sides of the cannon ball. This results in the cannon ball having in effect a conical region of compression surrounding its path. These lines do not retain their identity (as shown here for purposes of illustration) but merge into a single composite wave. The compression is greatest immediately in front of the cannon ball.

The disturbances shown in Figures 3, 4, and 5 are referred to as "shock waves." It is to be noted that the speed of the object and the shape of the object determine the angle between the object and the shock wave. Using our cannon ball as the object, we have the following condition relative to speed relationships and the angle between the cannon ball and shock wave. (Figure 6). We will deal with the shape relationship of the object and the shock wave a little later.

It is important to add to this discussion the term "Mach lines." These are imaginary straight lines corresponding in direction to the shock wave set up by the motion of the object. These are straight and meet at a point as indicated in Figure 7. The speed of an object in air is commonly referred to as

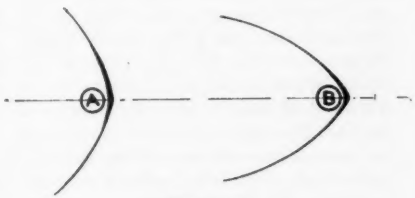

Figure 6

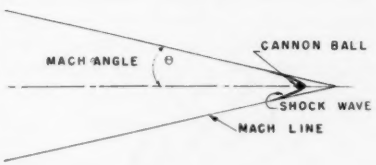

Figure 7

Mach number which is obtained by dividing the speed of the object by the local speed of sound.* Therefore we recognize that as an object moves through air at speeds greater than that of sound, it is proceeded by a layer of

*Thus at sea level, in air at the standard U. S. atmosphere, a body moving at Mach number 1 would have a velocity of approximately 1116.2 ft./sec.

highly compressed air. This compression decreases as the distance from the path of the object increases. When the object is moving slower than the speed of sound gradual changes are permitted to take place in the air stream; however, at supersonic speeds the particles in the air stream are subjected to sudden and considerable changes in their motion. Here the shock waves bunch the air into almost solid blocks of matter.

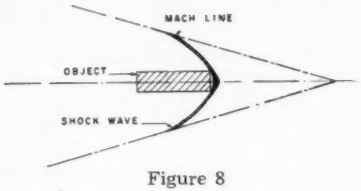

Figure 8

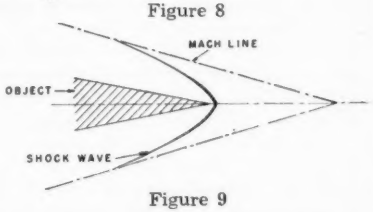

Figure 9

Before proceeding further, it is desirable to study the relationship between the shape of the object and the shock wave. Now let us discard our cannon ball and pick an object of different shape to study. The shape of the object influences greatly the form the shock wave takes. The shock wave endeavors to parallel the shape of the object. If we use a flat blunt object, Figure 8 we see that the angle of the shock wave changes gradually in an outward direction with the direction of motion. The angle of the wave can thus be used as an indication of the speed of the object. Figure 9 confirms this observation. We have now concluded that both the speed and shape of the object do influence the shock wave. It is now appropriate that we examine further this relationship of shape and speed to the shock wave as it affects objects traveling through the air. For large cone or wedge angles or for relatively low speeds, the shock wave is detached from the front of the body. (Figure 10). For small angles or high speeds the shock becomes attached to the front of the body and bends backward at a sharper angle. The above figure indicates relative speeds of the object by the use of shock lines 1 through 6. Once again we have confirmed our earlier observations relative to the speed and

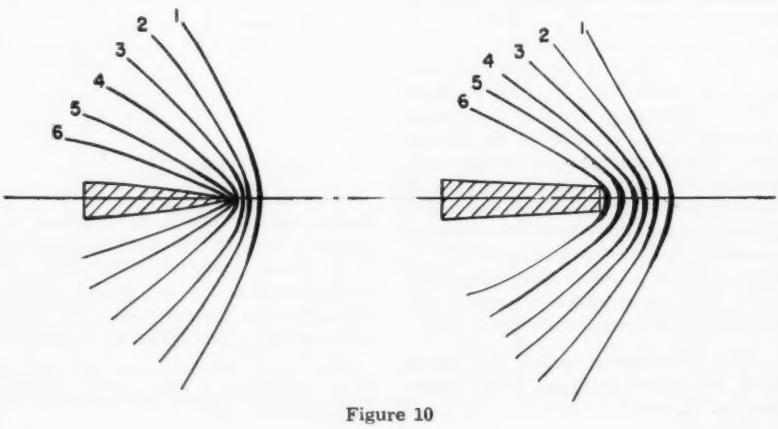

Figure 10

shape of an object on its shock waves. We are now ready to move one step closer to the study of the ram-jet in operation.

Let's examine an object passing through air at supersonic speed with an opening like a ram-jet rather than the solid objects we have considered earlier. The ram-jet opening will be a cone with an axial opening. If the pressure inside the cone is large a normal shock wave will be formed across it slightly upstream. (Figure 11). However, if the internal pressure is low the shock wave may be formed inside the duct. (Figure 12). Applying this information to a ram-jet in operation, if the combustion is proper and the design of the diffuser proper, a normal shock wave will be formed as shown in Figure 11. For all practical purposes the shock wave across the lip of the ram-jet forms a solid front allowing for proper ram-jet operation. This is one of the most critical of all design criteria for the ram-jet. Figure 12 is an example of improper combustion resulting in swallowed shock and inefficient operation. If the internal pressure is excessive there will be a spill over of air rather than a flow into the duct. In this the resultant operation will be inefficient. These three cases can be applied to the ram-jet. The first is the

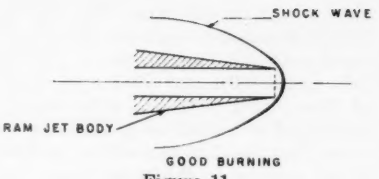

Figure 11

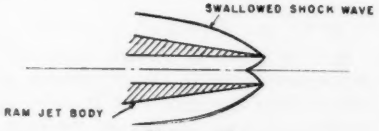

Figure 12

desirable condition and results from good internal burning and proper constriction of the outlet end. The case of swallowed shock is a result of improper combustion. Maximum thrust is obtained when the first condition exists in the ram-jet. Therefore all ram-jet design endeavors to place the shock wave on the rim of the inlet.

At this point, let us consider the air flow on the front and back sides of the shock wave. In the case of normal shock on the downstream side of the shock wave the movement will be subsonic; however, it is possible when the shock wave is oblique (not normal) to have supersonic speeds on the downstream

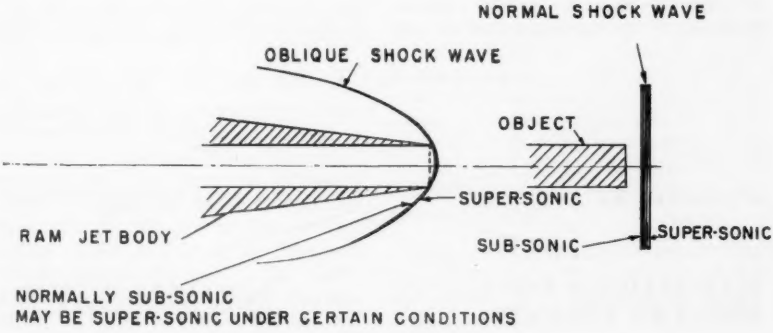

Figure 13

side of the shock wave. For clarity Figure 13 assumes the ram-jet body to be at rest and that the air is passing over and into the ram-jet. For purposes of illustration, it is easier to employ this relative relationship. It is to be noted that the direction of the air flow is not parallel to the shock wave but more nearly parallel to the surface of the moving body.

At this point we depart from exterior aerodynamic considerations to review fluid flow problems. In order to understand the operation of the ram-jet, it is also necessary to understand subsonic and supersonic flow through a tube of changing area. Among other things the flow of fluids is governed by Bernoulli's Equation, which is merely a statement of the law of conservation of energy as applied to fluids. Here we must consider the case of energy as applied to fluids and the case of both incompressible and compressible fluids. For incompressible fluids the relationship is quite simple. Using a compressible fluid (air) as does the ram-jet, produces a rather complex relationship when we study pressure and speed changes with area changes. Expressed in its simplest terms it may best be understood by the Figures 14 and 15. Therefore it is seen that entirely different relationships exist with fluid flows in a tube of changing cross section at subsonic and supersonic speeds. However, it can be stated that at low speeds the viscosity of the fluid is more important than its compressibility while at high speeds the compressibility of the fluid is more important than its viscosity.

Before studying the ram-jet directly, we need also review a few basic aerodynamics fundamentals. For the purposes of this study we are most interested in the retarding force exerted on a missile as it moves through the air commonly referred to as aerodynamic drag. This aerodynamic drag influences the shock wave which accompanies a missile at supersonic speed as well as does the shape and configuration of the missile. The drag on a missile moving through air results from surface friction, impact forces and partial vacua. A plane surface oriented parallel to the flow of the medium results only in surface friction; however, turn this surface at an angle with the direction of flow and the impact of the stream on the upstream surface must be considered as well as the effect of a partial vacuum on the rear surface. It is obvious that for other than plane surfaces the situation becomes more complex with friction, impact and vacuum entering to various degrees. The roughness, the angle of attack into the stream, the velocity and density of the stream determine the amount of drag for a plane surface; however, for other than a plane surface the drag also depends upon the shape. It is to be noted

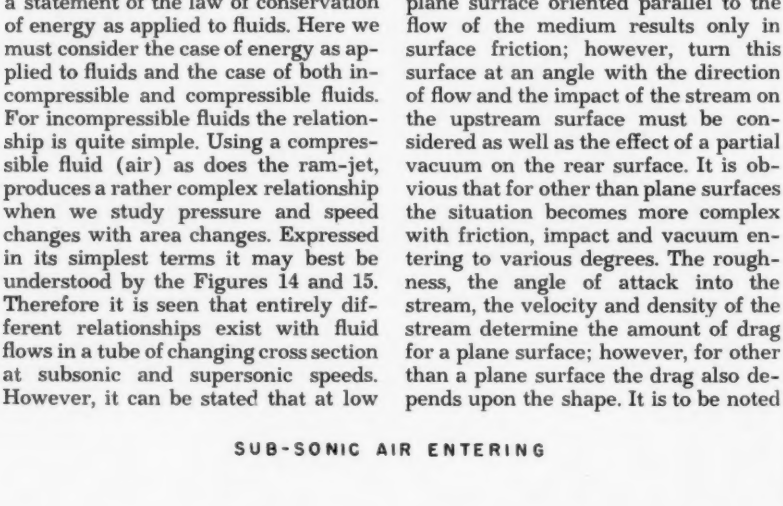

Figure 14

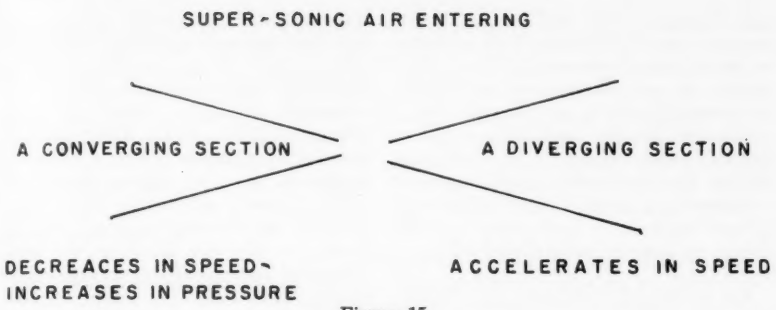

Figure 15

here again that supersonic and subsonic flows exert different relationships. The surfaces which give minimum drag at subsonic speed are not the same as those which give minimum drag at supersonic speeds. Therefore as is readily recognized, today the shapes of objects designed for subsonic flight are far different from those designed for supersonic flight or stated in the order of development it may be said that the subsonic designs are changed to meet flight requirements of supersonic speeds.

Now to study a ram-jet engine and its application to guided missiles. A guided missile has the following major components: a warhead, guidance system, and propulsion system. In this case the ram-jet engine is the propulsion system.

We have determined that the speed of air on the forward side of a normal shock wave is supersonic and on the downstream side subsonic. For the purposes of this study we may consider the shock wave itself to be the speed of sound. Immediately after the shock wave, there is a decrease in speed (refer to Figure 14) as the air enters the entrance diffuser of the ram-jet engine (refer to Figure 1). There is also a marked increase in the static pressure at the same moment. The decrease in gas velocity (ft/sec air speeds) continues until after fuel is mixed with the air and combustion takes place which results in a rapid rise in air velocity, a rapid rise in gas temperature and a decrease in both gas density and in static pressure. The pressure on the diffuser walls is considerably greater than the ambient atmospheric pressure resulting in a net forward thrust action on these walls.

As the air passes downstream and fuel is injected and mixed, it is ignited and burned as we learned above. As the gases expand due to the limited exhaust area they cannot expand through it fast enough to relieve the pressure accelerating them. Through this means a dynamic balance of forces is maintained; the forces acting to accelerate the exhaust gases are balanced by the pressure forces acting against the walls of the diffuser and producing the thrust. Should we stand on the stern of a rowboat and throw rocks in an aft direction the boat would go in the opposite direction (forward). This oversimplicity may be applied to the ram-jet and say that the momentum given the expelled gases is balanced by the momentum given the ram-jet in the opposite direction.

Now let us examine the two major component parts of a ram-jet engine and study their function to better understand the operation of the ram-

jet. These are the diffuser and the combustion mechanism. The purpose of the diffuser is to convert the kinetic energy of the incoming air into pressure energy and to receive the thrust produced by the expulsion of the heated gases which was discussed above. The combustion mechanism is composed of a combustion chamber, a fuel injector, a fuel pump, a fuel meter, an igniter and a flameholder.

Let us consider the operation of the ram-jet engine in a supersonic missile using as a point of beginning the hypothetical condition of the ram-jet at the moment of having been launched to an initial speed of 1000 miles per hour with the aerodynamic drag having overcome the thrust of the booster rocket at which point separation of the missile and the booster occur. The booster having expended its thrust is allowed to fall away. At the instant of separation a device known as the igniter in the ram-jet is activated to initially ignite a portion of the incoming air and the fuel mixture now moving through the combustion chamber. The igniter or pilot, as these devices may be called, is located in a region of low velocity flow to permit the initial ignition. The fuel injector, at the time of separation, is introducing fuel into the combustion chamber in a way to provide that combustion will proceed to a maximum degree of completeness in a minimum length of time and with a minimum transfer of heat to the walls of the combustion chamber. A fuel meter regulates the air fuel mixture delivered to the combustion chamber. This meter therefore must compensate for changes in flight altitude and flight velocity. A fuel pump supplies fuel to the injector at a particular desired pressure. Therefore at this moment we can consider that the ram-jet engine is being supplied a constant uniform fuel —air mixture which has been initially ignited. Let us next consider that we have a stable flame with complete or essentially complete combustion taking place in the ram-jet. At this point it is necessary that a means be provided to maintain the stable flame in a gas stream of high velocity. To accomplish this a device known as a flameholder is employed to create regions where the velocity flow is sufficiently low to permit the maintaining of small flames. These in turn are a source for continuously lighting the main high speed stream. No single component of ram-jet development has experienced so many different configuration and design changes as the flameholder. The process of combustion is now in full force and it remains the function of the combustion chamber to act as a confining area for the combustion process. With this the ram-jet accelerates on its own.

Here is a device, the ram-jet, simple in theory of operation, yet difficult to master in design and development. Today no longer do the questions of a decade ago plague advocates of the ram-jet. Most of these questions have been answered but today as we move forward a new set of problems faces the research scientist and the engineer. In 1945 the technical problems were numerous and complex. Answers were not available even to basic fundamental questions: Could an air breathing engine such as the ram-jet be produced that would develop thrust over drag? Here was an engine that must start after it was launched into the air at high speed. Could it be constructed so that it would start reliably? Could efficient combustion be maintained throughout a wide range of altitudes and wide air/fuel ratio changes associated therewith? Could such an engine's thrust be governed in flight and permit successful guidance? Could available materials withstand the tremendous temperatures generated in the combustion chamber of the engine?

In 1945 when the Bureau of Ordnance undertook the development of the ram-jet it was not simply a problem of development but one that required the demonstration and proof of the basic merits of the ram-jet principle—the proving of the principles, as first credited to the French engineer, Rene Lorin, and others as applied to a propulsive device.

A decade has passed and the ram-jet as a reality has been established. Today it is a simple engine, it is inexpensive; it possesses an excellent thrust to weight ratio. It has peak performance at supersonic speeds. Large numbers of units may be produced quickly and easily. It has no rotating or reciprocating parts. In the ram-jet the turbine and compressor of the turbo-jet give way to a simple duct using supersonic compression. The fuel system and controls are simpler than those of liquid fuel rockets. The ram-jet may be mass produced with a minimum of tooling. Costly alloys are unnecessary. Ordinarily hydrocarbon fuel may be used. The ram-jet has a low specific fuel consumption.

Today research and development continue just as research and development continue on the automobile engine. Today the ram-jet is a practical power plant. Tomorrow the ram-jet offers hope of becoming an even finer and more important method of propulsion. Man's advancement in the field of propulsion moves forward—this time in the form of the ram-jet, a powerful power plant.

THE WELDING OF COPPER AND ITS ALLOYS

ACKNOWLEDGEMENT

This review of the literature published from 1936 to 1954 is by Ira T. Hook, formerly Research Engineer, American Brass Co., Waterbury, Connecticut. Published in the Welding Research Supplement of the July, 1955, edition of "The Welding Journal," it includes optimum procedures for soldering, brazing or welding any of the copper alloys.

INTRODUCTION

In the earlier review terminating on Jan. 1, 1936,[6] an attempt was made (1) to summarize the knowledge of the art of welding copper and copper alloys in order to avoid duplication of effort in planning researches and (2) to enable one to plan the optimum welding method for a given alloy or a given connection. At that time, there was much confusion as to the efficacy of (1) various additions to the base metals, (2) to the filler rods, (3) to the fluxes and welding rod coatings, (4) of the various gases involved in welding and (5) of the various welding methods themselves.

There were questions as to the desirability of a long arc or a short arc; of alternating current or direct current; of straight polarity or reversed polarity.

In resistance welding, questions were unsettled as to flash heating or straight resistance heating; time and temperature of heating; and push-up speed and pressure. Radically different changes in the design of welding equipment were still to be tried.

Welding was an art still in the adolescent stage though it had its roots far back at the beginning of the Christian era. It probably started with the blacksmith's welds in the ferrous metals and in the flow brazes in bronze and fused joints in lead of the Romans. Beginning about 1905 in Europe and in this country, welding took an accelerated pace forward with the advent of the oxy-acetylene welding torch, the oxygen cutting torch, the carbon arc, the metal arc and the resistance butt and spot welder.

By 1936, nearly all of the welding processes now in use were known but many were unsatisfactory in specific applications because of lack of refinements or because of unknown factors. Many of these factors have been evaluated in the past 18 years. There are few applications at this time for which a satisfactory method of joining is not available. This is not saying that the welding art has solved all its problems. Much remains to be done.

What we have been witnessing in the past two or three decades has been the rapid metamorphosis of the art of welding into the science of the joining of metals and plastics. This science is still in the development stage. A great deal of welding is done in which the

skill of the welder plays an important part in the procedure. In the making of many other welds, the variables have been placed under automatic controls enabling one to predict the properties of the finished weld—and specifically, enabling an inexperienced operator to make satisfactory welds in part of a manufacturing process.

This review has for its primary aim the summarizing of information published since 1936, which will enable one to find the optimum procedure to solder, braze or weld any of the copper alloys.

One thing that makes it unnecessary to extend it greatly is that in the intervening years, handbooks[2-4] have been published containing a wealth of accredited information on welding.

In addition, most welding products manufacturers and welding equipment manufacturers have published useful, instructional brochures on welding, as the art relates to their particular metal or equipment. These last will not be reviewed herein since an inquiry may be sent directly to such manufacturers.

PLAN OF THE REVIEW

Since the purpose of the review is to draw attention to the most satisfactory procedures for welding copper alloys, the review will ignore for the most part the enormous volume of literature dealing with the ferrous metals and with aluminum, magnesium, titanium and other metals not commonly associated with copper and the copper alloys. Owing to time limitations, the review will also have to ignore the very important contributions in the French, German and Russian languages.

In order to make the review useful —make it understandable to those who are called upon to design joints in copper alloys or to actually make the connections therein—the review will deal: (1) with the metallurgy of the copper alloys as it affects the quality of the weld, and (2) with the effect of various joining methods, pointing out those which have been most satisfactory over the years.

In this connection, the review should also point out those metallurgical constituents and practices which are detrimental to weld quality and those welding methods which are inappropriate to a given copper alloy.

In discussing (2) above i.e., joining processes for copper alloys, the review will follow commercial practice and group them in the broad classification in which they are used. The temperature scale will be taken as the primary coordinate with the various distinctive joining processes dependent thereon, Table 1.

Table 1 is a much abbreviated statement of the Welding Handbook's chart of welding processes.[2] Three of the eight general welding processes, i.e., Forge Welding, Thermit Welding, and Flow Welding are not included in Table 1. The reasons for these omissions are stated below.

TABLE 1—JOINING PROCESSES AND TEMPERATURE RANGES

Joining process	Temperature range Minimum	Maximum
Cold welding	Room temperature or above	
Soft soldering	183° C (361° F)	240° C (460° F)
Silver brazing, hard soldering	635° C (1175° F)	843° C (1550° F)
Brazing, braze welding	871° C (1600° F)	954° C (1750° F)
Copper-hydrogen brazing	1094° C (2000° F)	1149° C (2100° F)
Fusion welding, resistance welding	885° C (1625° F)	1261° C (2300° F)

Forge welding which has been so successful in the familiar blacksmith's welds on wrought iron and steel since the beginning of the Christian era has never been successful with copper, brass or bronze. The oxides formed on the copper alloys are more closely clinging and interfering than the oxides on the ferrous metals. Theoretically speaking, it should be possible to dissolve the copper oxide films with borax and then effect a hammer weld at about 1200° F but, practically, it is not easy. It has never been an acceptable process.

Flow welding was used by the Romans in the manufacture of bronze bathtubs, in which process the edges of the adjoining parts were brought to the fusion welding temperature by flowing molten bronze over them and using part of same for the filler metal. Flow welding is sometimes used in the brass foundry to fill out a worn, broken or imperfect casting, as a ship's propeller. In this case, the casting is heated and the place to be filled set on a slope. Superheated metal of the same composition, manganese bronze perhaps, is flowed over the base metal until the area is brought to temperature and cooler filler metal allowed to solidify. With modern facile control of heat in the torch or arc, flow welding need be given no further consideration.

It will be noted in Table 1 that there are both gaps and overlappings in the temperature scale. That is actually the way it is in commercial practice. The most serious gap is that between soft soldering and silver brazing. There is an unsatisfied demand for a medium-hard solder in this range, i.e., 430 to 1175° F. Actually, there are alloys to meet it, as will be pointed out later. But, at the moment, there is no flux that is entirely dependable in this temperature range. The aluminum industry has silver alloys and fluxes that melt around 1000° F, but these have not been used on the copper alloys. This temperature gap is not as bad as the temperature range makes it appear for the reason that torch equipment used in soft soldering can be employed with equal facility in silver brazing.

Again, the temperature gap between the silver solders, phosphorus-coppers and the brazing alloys is more apparent than real. With proper design of the connection, either silver brazing or brazing may be used.

Copper-hydrogen brazing is in a different category from brazing and braze welding as will be seen later. The overlapping between this process and fusion welding will also be explained.

ELEMENTS ASSOCIATED WITH COPPER

In Table 2, the various elements associated with copper in making the thousand and one copper alloys are listed. The melting and boiling points are given for each element, together with the proportional range in which it is added to copper.

The melting and solidifying temperatures of a given element are always at a common, definite value, characteristic of the given element. The melting and solidifying temperatures of an alloy are usually not the same. In the temperature range between the liquidus and the solidus of an alloy, the material will be a mixture of liquid and solid particles.

There are several important exceptions to this last stated rule. A few binary alloys have a definite, common melting and solidifying temperature known as the eutectic temperature. At the same time, the definite proportions of the two elements are known as the eutectic proportions. The eutectic temperature is generally lower than the melting point of either constituent elementary metal.

The Metals Handbook[3] shows several important eutectic compositions of interest to the users of copper and copper alloys, thus:

TABLE 2—ELEMENTARY METALS ASSOCIATED WITH COPPER IN THE COPPER ALLOYS

Element	Melting point ° C (° F)	Boiling point ° C (° F)	Proportions used in a copper alloy % Min.	Max Wrought alloy	Cast alloy	Alloy type
Aluminum	600 (1220)	2060 (3740)	0.00	11.00	11.00	Aluminum bronze
Arsenic*	615† (1139)†	....	0.00	1.00	....	Arsenical copper
Beryllium	1280± (2340)	2770 (5020)	0.00	2.25	2.75	Beryllium copper
Boron	2300 (4200)	2550 (4620)	0.00	0.05	....	
Cadmium	321 (610)	765 (1409)	0.00	1.00	....	Cadmium copper
Chromium	1890 (3430)	2500 (4500)	0.00	1.25	1.25	Chromium copper
Copper	1083 (1981)	2600 (4700)	55.0	100.00	100.00	Electrical copper
Iron	1539 (2802)	2740 (4960)	0.00	3.00	5.00	In aluminum bronze and manganese bronze
Lead	327 (621)	1740 (3160)	0.00	3.50	30.00	Leaded copper, brass and bronze
Magnesium	650 (1202)	1110 (2030)	0.00	0.05	....	As deoxidizer only
Manganese	1245 (2273)	2150 (3900)	0.00	5.00	....	Manganese copper Manganese bronze
Nickel	1455 (2651)	2730 (4950)	0.00	30.0	30.00	Cupro-nickel and nickel-silver
Oxygen*	-219 (-362)	-183 (-297)	0.00	0.07	0.10	In tough pitch copper, electrical
Phosphorus*	44 (111)	280 (536)	0.00	0.50	5.0	Phos. deox. copper phos. copper, phos. bronze
Silicon	1430 (2605)	2300 (4200)	0.00	4.00	4.50	Silicon copper
Silver	961 (1761)	2210 (4010)	0.00	1.50	....	Silver-bearing copper
Tellurium	450 (840)	1390 (2520)	0.00	0.75	....	Tellurium copper
Tin	232 (449)	2270 (4120)	0.00	11.00	30.0	Bronze
Zinc	419 (787)	906 (1663)	0.00	42.00	50.0	Brass

*Usually regarded as a nonmetal.
†Sublimes.

1. The eutectic formed by the alloying of 28.1% copper with 71.9% silver melts and solidifies sharply at 779.4° C (1465° F).

2. Copper 91.62% plus phosphorus 8.38% has a eutectic temperature of 714° C (1317° F). In this case the eutectic temperature is higher than the melting point of the elementary phosphorus.

3. A brass made up of 62% copper and 38% zinc melts and solidifies sharply at 903° C (1659° F).

4. The important "tinners" solder is made up of 61.9% tin and 38.1% lead

melting and solidifying sharply at 183° C (361° F). The more familiar 50:50 tin-lead solder has liquidus-solidus range 215° C (419° F)-183° C (361° F).

The boiling points of the elements are not as well authenticated as the melting points but are given for comparison. In only three of the elements, viz., cadmium, phosphorus and zinc are the boiling points of particular interests to the welder.

Table 2 is, for the sake of completeness, expanded from that given in the Welding Handbook,[2] to include the minor as well as the major additions to copper to make commercial copper alloys. A few elements, such as tungsten, added to copper in the form of metal powders, compressed and sintered, are excluded.

Samans[21] remarks: "In general, the purer a metal is, the lower will be its hardness, alloys tending to be not only inherently harder than the metals upon which they are based, but also more susceptible to changes in hardness caused by mechanical work or heat treatment."

The amount of the addition of some elements to copper is sometimes greater for a casting than for a wrought metal. This fact is of interest to the welder, as many times he is called upon to make harder weld deposits than are obtainable from a wrought alloy filler rod. He accomplishes this by using cast rods or he uses composite rods or metal powders in the coatings.

GROUPING THE COPPER ALLOYS

Copper and the various copper alloys may be assembled into a comparatively small number of groups, each of which has, respectively, some similarity in the reaction of the individual alloys to welding metallurgy. The many hundreds of copper alloys[9] in general use are summarized in Metals Handbook[3] into 65 representative alloys with metallurgical and physical properties given in detail for each, together with the ASM, the ASTM, Federal or other specifications which apply. The ASME in its Handbook on Metal Properties[5] likewise reports the physical, technological and mechanical properties of 65 representative copper alloys, though these are not in every case identical with those in the former handbook.

H. J. Miller[8] published, for the benefit of the British copper industry, an excellent summary of copper alloys in 17 tables or groups. He included compositions, properties and appropriate applications. He mentioned welding.

None of the above lists of copper alloys are, on account of their length, given here. A student of copper welding should, however, be familiar with such detailed alloys and their properties.

The welding Handbook[2] lists eight groups of copper alloys with 27 representative alloys incorporated therein, with details of chemical, physical and welding properties given.

J. Imperati and the writer grouped the many copper alloys into eight divisions[7] as shown in the first eight groups of Table 3. Groups 9 and 10 have been added to this table for the sake of completeness.

In this review, the classification of Table 3 will be used. The properties of these ten groups, as the properties are related to welding, will be explained. Among the thousand and one copper alloys,[9] there will be some which will not have a composition falling within the limitations of Table 3. However, notes on the metallurgy of the elements of Table 2 will usually provide a clue as to the group into which any specific alloy may be placed.

TABLE 3—COPPER ALLOYS GROUPED ACCORDING TO WELDING CHARACTERISTICS

Group No.	Composition, %	Name, remarks, and ASTM specifications
1	99.9+ copper	*(a)* Tough pitch copper. Carries 0.02 to 0.07% of oxygen in form of microscopically small specks of cuprous oxide. ASTM B152, Type ETP and FRTP. *(b)* Deoxidized or oxygen-free copper. Has no cuprous oxide in it. Phosphorus deoxidized copper has 0.015 to 0.040% residual phosphorus. ASTM B152, Type DHP.
2	95 to 80 copper 5 to 20 zinc	Commercial bronze and red brass. Special alloys may contain lead for free machining or tin for improved strength and resilience. ASTM B36.
3	75 to 58 copper 25 to 42 zinc 0 to 1 tin	Spring brass, cartridge brass, common brass, Muntz metal. An addition of 0.5 to 1.0% tin is found in Tobin Bronze and Admiralty. Also fractional percents of tin, iron and manganese in manganese bronze. 2 to 3% of lead is generally found in extruded architectural bronze and brass forgings. ASTM B36 and Navy 46B6.
4	72 to 55 copper 10 to 32 zinc 10 to 20 nickel	Wrought nickel silver usually has 18 to 25% nickel with 20 to 25% zinc. Extruded nickel silver is higher in zinc, about 40% and lower in nickel, 10 to 12% with 2 to 3% lead. ASTM B122.
5	90 to 70 copper 10 to 30 nickel	Cupro nickels. ASTM B122 and Navy 46C6.
6	96.5 to 89 copper 3.5 to 11 tin 0.03 to 0.35 phos.	Tin bronze or phosphor bronze. Grade A phosphor bronze has 4 to 5% tin, Grade C about 8% tin, and Grade D about 10.5% tin. ASTM B103.
7	98 to 95 copper 1.5 to 3.5 silicon 0.50 to 1.5 manganese, zinc or tin	Copper-silicon alloys. ASTM B96.
8	96 to 88 copper 4 to 9.0 aluminum 0 to 3.5 iron	Aluminum bronze, forging bronze and Avialite bronze. Frequently contains about 1% of iron, manganese and/or nickel. ASTM B169.
9	97.40 to 98 copper 0.25 to 0.50 cobalt or nickel 2.00 to 2.25 beryllium	Beryllium copper. Precipitation hardenable[3] (p. 934).
	99.0 copper 0.8 to 1.0 chromium 0.0 to 0.10 silicon	Chromium copper. Precipitation hardenable.
10	99.0 copper 1.0 cadmium	Cadmium copper. Used for electrical conductors having good strength.

WELDING METALLURGY OF COPPER AND THE COPPER ALLOYS

In a fusion weld, the metal has to run the gamut from room temperature through preheat to melting, through solidification, possible hot working, and back to room temperature. The metal expands and contracts, bringing into play strength and ductility, hot and cold. These are effects which are of as much interest to the welder as to the metallurgist.

Specific properties of interest to the welder in the metals of a weld are: (1) Surface conditions of the solidus, (2) of the liquidus, (3) thermal conductivity, (4) melting point, (5) boiling point, (6) cold ductility, (7) hot ductility, (8) hot and cold strength, (9) coefficient of expansion and contraction, (10) reactions with air, welding gases including heating and shielding gases, (11) reactions with the fluxes, fluxcoating and finally (12) the soundness, ductility, hardness and strength of the finished weld.

However, rather than discuss these properties categorically, attention will be called to them as the joining process itself is described.

OPTIMUM JOINING PROCESSES FOR THE COPPER ALLOYS— AN EVALUATION

The six processes listed in Table 1 are discussed in proper sequence below. Note that the *sequence is arranged in order of temperature from room temperature to that of the liquidus of the most refractory copper alloy at about 1260° C (2300° F).* Any of these temperatures are readily attained by modern welding equipments, furnaces and induction heaters.

Aside from such strictly mechanical connections as riveting, bolting, threading, clamping, wrapping of wire, seaming of sheet metal, etc., we have numerous variations of joining in which the atomic bond is brought into play. These are the connections with which we are concerned here. Table 1 shows the various joining methods which are applicable, together with the temperature range to which the base metal and the filler metal are heated.

COLD WELDING

The metallic (atom) bond is a powerful force of extremely short range of the order of perhaps less than 10 A units center to center of atoms. Glasstone[10] remarks "that metals are characterized by the presence of a special type of metallic bond, in which a relatively small number of electrons are able, *in some manner,* to bind together a large number of atoms or, more correctly, ions."

The metallic bond is progressively weakened as the atom energy is increased with the temperature until at the melting point, and up to the boiling point, the gravitational force on the atom supersedes the metallic bond.

Cold welding contemplates forcing atom pairs, one from each of the metals to be joined, sufficiently close by mechanical pressure to bring the metallic bond force into play. If a sufficient number of atom pairs are brought together across the joint, a more or less strong weld will be obtained—and the strength partly retained after the external pressure is relieved.

A molded part made of powdered metals compacted under the normal commercial pressure is a case in point.[3] The part will endure reasonable handling because of the atom bonds at pressure points between powder particles. But in few cases is the integrity of the molded part sufficient for its intended use. It must be handled gently. Only after sintering is its strength and hardness sufficient for its intended use.

Sintering temperatures for copper alloys are given in Metals Handbook[3] as 1300 to 1650° F. Such temperatures are far above the recrystallization temperature and approach incipient fusion. They undoubtedly promote mutual diffusion of the materials of the faying surfaces.

Wulff[14] remarks, "The cohesive strength of the material (powdered metal) depends on..... the atomic bonding between contacting surfaces. The greater the plasticity of the powder, the greater the probability of forming such bonds."

The principal difficulty in establishing the metallic bond in making cold (room temperature) welds, seems to be the elimination of surface films from the faying surfaces. Sowter,[13] in describing the process for aluminum, says that after cleaning the surfaces of all grease and dirt, which may be accomplished by the usual mechanical or chemical methods, the clean metallic surface must be further reduced to raw metal by scratch brushing preferably by a high-speed revolving wire brush having suitable steel wires as to size and hardness. Chemical cleaning is unsatisfactory as the chemical must be washed off, which washing invariably leaves an interfering film.

The second requisite according to Sowter[13] is a pressure (at room temperature) sufficient to deform the metal. In the case of aluminum this is stated to be 24,000 to 36,000 psi, while for copper it should be two to four times this value. Dubillier[15] agrees that pressures for aluminum should be 27,000 to 40,000 psi, with 2 to 4 times these values for copper.

Parks[16] in an exhaustive study of the spot welding of copper and brass at recrystallizing temperatures used a different approach from Sowter by (1) using cold worked surfaces, (2) lighter pressures and lighter deformations and (3) temperatures elevated to those causing recrystallization. He also used circular spot welds which were objected to by Sowter as restricting flow of the metal under pressure in a manner to destroy the cold welded bond.

However, Parks[16] proved that excellent solid-phase spot welds were obtained in electrolytic copper when the spot welds were made at temperatures between 300 and 400° F, and in cartridge brass at temperatures from 500 to 800° F. The welding process (bonding time) was 15 min for the copper and 2 min. for the brass. He relates the recrystallizing temperature, degree of deformation and recrystallizing time (time at welding pressure) finding this last variable to be from 10 sec. to 10 min.

Kinzel,[17] whose work was done in 1944 several years before cold welding was announced, contemplates another type of solid-phase welding from the cold welding described by Sowter and Dubillier and the recrystallizing welding investigated by Parks. He uses carefully prepared surfaces, held together at a definite pressure and heated at the interfaces and back of the interfaces to a forging temperature. The pressure is insufficient to cause deformation at room temperature but high enough to deform the heated, but still solid, metal.

Kinzel agrees that physical tests of the solid-phase weld provide an indication of the quality of the weld, but he also insists that the interfaces should be obliterated (1) by crystal growth across same and (2) by diffusion of any non-metallic film, such as an oxide, which may have been present at the interface.

Most of his work was done upon steel but experiments with copper, 70/30 brass and 60/40 brass indicated that solid-phase welds were possible at temperatures approaching, but well below, the solidus temperature. Kinzel

remarks that "Copper can be welded at temperatures close to the melting point only with great difficulty." The 60/40 brass, which has an alpha-beta transformation at temperatures around 1400° F, welds at a lower temperature than copper or the 70/30 brass which have no such transformation. Kinzel postulates that the diffusion of atoms and non-metallic solute molecules is accelerated by such transformation.

Davis and Holmes,[18] having the advantage of the foregoing reports, made in 1949 a more thorough investigation of the characteristics of copper alloys in solid-phase, elevated-temperature welding. Tests were made on phosphorus deoxidized copper, 70/30 and 80/20 cupro nickels; 93/7 and 91/9 phosphor bronzes; 85/15 red brass, leaded brass alpha-beta brasses, silicon bronze and aluminum bronze.

Temperatures varied from a low of 475° C for one test on leaded brass to 1200° C for one test on cupro nickel. Heat was furnished by an oxy-acetylene ring burner of 6 nozzles which also flooded the contacting surfaces throughout the welding operation. Time varied from 15 sec. to 10 min.

Deformation was determined as the per cent increase in the area of the contacting faces in terms of the final area.

Davis and Holmes were able to get satisfactory welds on all copper alloys except the aluminum bronze which had a somewhat erratic performance due to aluminum oxide in the connection.

They found that the deformation was the most critical variable, the welded strength being a maximum with deformations as high as 80%. Deoxidized copper was an exception with deformations as low as 6 to 12% resulting in full annealed strength across the weld.

Conclusions as to Solid Phase Welds

It seems to the reviewer that solid-phase welds can be made in copper and copper alloys provided the conditions are correctly adjusted for each alloy:

The attainment of these conditions may be impractical when the cost is compared to that of a fusion weld.

The state of the art is silent on one important point—protection of the clean contact surfaces during the heating-up period. The burnt gas from the oxy-acetylene torches used by Kinzel and by Davis and Holmes gave a measure of protection from the oxygen of the air, but the water vapor inherent in such burnt gas will oxidize many of the copper alloys if the temperature is sufficiently high.

The protection needed may possibly be supplied (1) by a suitable flux, (2) by an inert dry gas as helium or argon or (3) by a noble metal film. We have found no reference in the literature to any of these methods. The flux method offers little success, as the fluxes which are satisfactory at temperatures up to 500° F are unsuitable at higher temperatures, and those good for the 1100 to 1700° F range offer no protection at lower temperatures. A mixed flux is still possible but is not known at present.

The noble-metal film need not be a metal of the gold or platinum group, though these are particularly inert to oxygen at all temperatures. Silver, tin and iron are possibilities still to be tried. Iron, for example, is used in this manner in the manufacture of stainless-clad carbon steel.[77] In this case, steel alloy plates are coated with a few mils of pure iron and hot rolled together. Grimshaw[78] describes the method in detail.

Of the other variables involved in solid-phase welding as *(a)* pressure, *(b)* deformation, *(c)* temperature and

(d) time, the pressure appears to be a means to an end only. It must be high enough to cause a critical deformation. The deformation in which the metal in the contact plane will stretch seems to be fundamental. In other words, the surface film of the contact surfaces must be pulled apart. But this is always accomplished indirectly—much as Poisson's ratio effect is attained by elastic stresses.

The pressure on the surfaces causes a sidewise expansion. Sowter shows that a restraint of this sidewise expansion (as in a spot weld made in a large area) reduced the strength of the weld over that made at the edges of the same sheets where the restraint to sidewise slip is reduced on one side.

A pressure sufficient to cause the desired deformation at room temperature is easily attained in spot and seam welding of soft sheet metals, *i.e.*, pure aluminum and soft metals. It is more difficult with copper and the copper alloys, though by mechanical or hydraulic pressure it is still possible.

In butt welding of sheet metal, rods, bars, shapes and tubes, the means of attaining the desired deformations are more difficult. And the expense may be prohibitive when the materials are kept at room temperature.

For this reason, it may be desirable to raise the temperature, which in turn will reduce the yield point of the copper alloy and allow the desired deformation to take place at moderate pressures and times.

The elevated temperature accomplishes two other desirable conditions, it makes the atoms more active and improves the diffusion of film components into the metal. Whether the temperature needs to be above the recrystallizing temperature or not seems to be an open question though, undoubtedly, a high temperature promotes grain growth across the contact plane.

SOFT SOLDERING TEMPERATURE 360—470° F*

Soft soldering of the copper alloys of Table 3 in the case of all of the ten groups except Groups 7, 8 and 9 is so simple and so universally used as to need little explanation. The Welding Handbook[2] disposes of the subject for all base metals in 2½ pages. The Metals Handbook[3] deals with the subject at somewhat greater length. Perhaps the most complete study of soft soldering is that published by R. M. MacIntosh.[12]

MacIntosh remarks,[12] "The process of soldering is relatively simple, but it requires considerable skill and ingenuity to produce a joint of optimum properties. A thorough knowledge of the fundamental properties of solder alloys and methods of applying them is needed in order to use solder efficiently at modern production speeds." This is undoubtedly true. Many inefficient joints are made. In some cases, this is due to the lack of skill of the operator, and in others, to his insufficient knowledge of the factors involved in soft soldering.

Typical soft solders are given in ASTM Specifications B32-49.[19] Of the 30 soft solders listed, the following are typical of those most commonly used with copper alloys.

The first three solders of Table 4 are taken from the above specification. The 95 tin–5 antimony solder is quoted by MacIntosh from the U. S. Federal Specification QQ-S-57lb. He also shows the two silver-lead and silver-cadmium solders.[12]

The 60 tin–40 lead solder is useful in a

*Less frequently and with more difficulty, due to flux limitations, medium temperature solders are applied at temperatures between 360 and 750° F.

TABLE 4—TYPICAL SOFT SOLDERS

Nominal composition, % Tin	Lead	Melting ranges Solidus	Liquidus	Applications, remarks
60	40	183° C (361° F)	190° C (374° F)	Tinners solder, quick solidification. Used on thin sheet copper and brass.
50	50	183° C (361° F)	216° C (421° F)	General purposes. Most popular of all for copper alloys.
40	60	183° C (361° F)	238° C (460° F)	Plumbers wiping solder. Not commonly used on copper alloys.
95	5 Sb	233° C (452° F)	240° C (464° F)	Antimonial tin solder. Stronger joints for hot water lines than the 50:50 solder.
2.5 Ag	97.5 Pb	304° C (579° F)	304° C (579° F)	High temperature, soft solder. Torch soldering.
5 Ag	95 Cd	340° C (644° F)	400° C (752° F)	High temperature, soft solder. Torch soldering. Good corrosion resistance.

variety of applications on copper and copper-alloy sheets and wires where quick solidification is desired. The 50 tin–50 lead solder is preferred for soldering soft and cornice temper copper roofing sheets and for leader and gutter work. The higher tin content of the former is preferred for cold-rolled copper, brass, and bronze sheet and strip and cold-drawn copper and bronze wires. The 50:50 solder is commonly used for sweat soldering of copper plumbing installations, but it should never be used where the connection is subjected to a stress as in a long riser for a tall building.

The 95 tin–5 antimony solder is preferred for hot water plumbing and for heating installations because of its better strength at elevated temperatures up to 215° F.

The last two solders listed in Table 4 are intended for applications where service temperatures are apt to go above 215° F. They are not as easy to apply as the lower melting solders, but the difficulty lies more with the fluxes than with the solders or the heating torches. The chloride fluxes break down at temperatures under 600° F, exposing the surfaces to the torch gases or the air.

Referring to Table 3, all of the copper alloys except those of Groups 7, 8 and 9 are easily soft soldered. The copper-silicon alloys of Group 7 are soft soldered without difficulty provided the metal is cleaned and fluxed before being heated.

Hard copper, hardened by cold rolling of sheet and strip or cold drawing of tubes, wires, bars and shapes, will usually retain the cold-work hardness through a soft soldering operation as they will not in a brazing or fusion welding operation. However, pure copper with a softening point about 200° C (392° F) is sometimes softened unduly in a soft soldering operation, as in the manufacture of automobile radiator cores, for example. In such cases, copper, with an addition of 0.03 to 0.10% silver, or a red brass, is preferred.

The aluminum bronzes and beryllium coppers of Groups 8 and 9 are difficult to soft solder. Silver brazing is a preferred method of joining. Richards[20] suggests that beryllium copper

should be soft soldered only when the stress on the connection is low.

Solders are available in a wide variety of bars, wires, cored wires and powders. G. H. Bohn[32] gives an excellent discussion of the variables involved in soft soldering the copper alloys as (1) the solders and their properties, (2) heating methods and types of flames, (3) fluxes, (4) design of joint to be soldered, (5) copper and brass base metals, etc. Bohn recommends a careful study of the Bureau of Standards publications on solders and soldering.[33]

Fluxes for soft solders are obtainable in a wide variety. MacIntosh[12] lists seven general types of inorganic fluxes and 14 organic fluxes. There are many more proprietary fluxes.

Rosin is the flux most commonly used when a noncorrosive one is desired, as on electrical equipment. Proprietary varieties of noncorrosive fluxes are available in powder, liquid, solder-cores and mixed with powdered solder.

SILVER BRAZING, PHOSPHOR COPPER BRAZING

SILVER BRAZING OR HARD SOLDERING, 635° C (1175° F)-843° C (1550° F)

All of the copper alloys in the ten groups of Table 3 are brazed more or less readily by the alloys in the silver solder group.[19] Some typical silver and other hard solders are listed in Table 5. The first three are from the ASTM Specification B73-29,[19] while the other three are reported in the Welding Handbook.[2]

The use of a silver brazing alloy on copper and the copper alloys results in a ductile, high-strength, corrosion-resisting connection. The heat used in making the connection will usually anneal the copper alloy in the joint though, in some alloys, part of the cold work strength and hardness may be retained. The speed with which the silver soldering is accomplished determines the amount of cold work hardness and strength retained in the finished braze. The precipitation hardening alloys of Group 9 are treated separately later.

Nearly every form of heating except the arc, is used on one job or another to melt the silver alloy and heat the base metal.

There are numerous references in the literature to brazing with the silver alloys and phosphorus copper alloys of which the following are typical.

Van Nattan[40] writes a very complete discussion of base metals, appropriate brazing solders, heating methods, fluxes, connection designs and appropriate application. Copper alloys are indicated as base metals and brazing solders. Wirt[41] gives a survey of brazing at Delco-Remy Division of General Motors Co. The American Welding Society Committee[42] gives compositions of 32 brazing metals suitable for the joining of most commercial engineering and noble base metals. Data on available forms and brazing temperatures are quoted.

Kriegel[59] discusses the use of the BAg-1a silver solder on various designs of joints in copper, Everdur, Monel and other copper alloys.

Weir and Webber[22] report the silver brazing of 1237 (¾ OD x 0.049-in. wall) deoxidized copper tubes into 48-in. diam. by ¾-in. thick steel tube sheets to make a 225 psi steam heating boiler good for an evaporation of 6800 lb per hour. The brazing alloy was the BAg-1a in Table 5. The brazing operation eliminated a mechanically rolled connection using steel ferrules.

TABLE 5—TYPICAL SILVER AND HARD SOLDERS

Grade	Composition, % Silver	Copper	Zinc	Cadmium	Solidus	Liquidus	Remarks
1	10	52	38	..	820° C (1510° F)	870° C (1600° F)	For silver brazing steel, etc.
5	50	34	16	..	695° C (1280° F)	775° C (1425° F)	For general silver brazing.
8	80	16	4	..	740° C (1360° F)	795° C (1460° F)	For silver brazing copper.
BAg-la	50	15.5	16.5	18	627° C (1160° F)	635° C (1175° F)	For general low temperature silver brazing.
				Phosphorus			
BCuP-5	15	80	..	5	640° C (1185° F)	785° C (1445° F)	For brazing copper only.
BCuP-4	..	93	..	7	743° C (1370° F)	788° C (1450° F)	For brazing copper only.

The brazing provided ample strength in the bond between the dissimilar metals and eliminated much of the maintenance trouble.

C. C. Natebaret[23] used powdered silver solder mixed with flux and the clamped edges heated with an oxy-acetylene torch. Mesh of extremely fine wires woven 76 per inch was successfully joined.

R. J. Wensley[24] reports the use of carbon-resistor jaws electrically heated to clamp the copper switch parts and heat same until the preplaced silver solder melts. This method was satisfactory with brass, bronze, and steel, but difficulty was experienced with leaded brass due to the sweating out of the lead, and with aluminum bronze due to the film of aluminum oxide on same which is difficult to flux.

R. H. Leach[25] contributes general discussion of silver brazing alloys and procedures with a brief survey of the literature. C. F. Zappone[26] gives an excellent summary of the methods used in silver solder brazing current in 1940.

R. L. Briggs[27] explains a method of silver brazing by resistance heat pulses which work so rapidly that the hard copper is not appreciably softened.

C. M. Robins[28] reports the widespread application of silver brazing to war equipment manufacture, as 400 brazed parts in an airplane and several hundred in a single torpedo, with eight miles of silver-brazed piping on a ship and nearly all tungsten-carbide tools silver brazed to the shank.

G. H. Bohn[30] discusses the proper design of joint for silver brazing sheet, tubes and thick shells.

H. A. Smith and P. A. Koerner[31] analyze design factors, procedures, operator qualification, etc. They relate same to strength of silver brazed joint in steel obtaining an average shear strength in the solder of 43,200 psi in joints designed for 35,000 psi. They prefer the oxy-acetylene or the induction method of heating.

Christie and Setapen[34] discuss the inspection and testing of silver brazed joints, directing attention to requirements for standard test procedure. Consideration is given to such variables as (1) type of joint as butt, scarf, lap, (2) design of complete connection, (3) surface consideration, (4) jigging, (5) fluxing, (6) proof tests, (7) brazing controls, (8) tests after brazing, as visual, mechanical, pressure, metallographic, though no actual tests are quoted as was the case with Koerner's report.

J. P. Weed[29] describes an early application of silver brazing by the use of induction heating after trying other methods. An objection to induction heating is its high initial cost.

Bunte[37] gives a very complete resumé of induction heating methods for low- and high-temperature brazing in ferrous and nonferrous metals. The frequency of the heating current may be stepped up by (1) motor generator, (2) spark gap or (3) vacuum tube. Generators not yet available for 30 kc; spark gaps 80 to 525 kc; tubes 400 to 500 kc or above. Capacities of 7½ kw in generators; spark gap up to 30 kw and electronic sets from 200 w to 100 kw in size. Benefits of induction heating are said to be (1) more heat in a given area with better control, (2) greater uniformity of results, (3) greater production for a given floor space, (4) maximum economy in mass production, (5) possible use of unskilled labor. The lone objection is the high first cost of the equipment in this new field.

Brazing by Induction Heating

J. P. Weed[29] and others give useful data. After the initial cost of induction heating equipment is absorbed, economies in its use are readily demonstrated. Gise and Stewart[35] show how it speeds up production in the manufacture of kitchen utensils. Using a 20 kw, 450 kc R-F generator for silver brazing 1500 sets of 6-piece kitchen utensils per 15-hr day, the cost is reduced from $390 for torch brazing to $162 for the induction method. Moreover, with the latter method, workmanlike connections are obtained with inexperienced operators while skilled operators are required for torch brazing. Vernor and Adams[36] tell a similar story in making a silver braze in 30 sec for tungsten carbide tips to steel shanks using 10 kw at 450 kc.

Speed-Up Methods

In addition to the use of induction heating for silver brazing, rotating tables and moving belts are in use for speeding production. Setapen[38] explains the use of a rotating table with fixed oxy-acetylene burners. Swarthout[39] cites the brazing of air-conditioning and refrigerator parts and copper tubes with the oxy-acetylene torch using both silver alloys and the yellow bronzes.

The *Welding Engineer*[43] reports the reduction of the brazing time from 4 min to 40 sec in a given job, with a uniformity in brazing such that inspection could be eliminated. The heat was obtained from an induction heater. Another report in the same magazine in August 1944 tells of cutting the time of a different brazing job from 7 to 12 min to 51 sec. Kielb[44] tells of using a gas torch in production—line brazing in preference to arc welding, while Scott[45] cites the use of brazing—in this case using a phosphorous copper brazing alloy—replacing soft soldering with economy and improved strength.

Johnson and Huff[47] discuss automatic torch brazing with standard oxy-acetylene torches and turntables or conveyor belts. They mention practical applications. Another article in the October 1950 issue of the *Welding Engineer* reports that turn-table brazing and induction heating were responsible for cutting one-third off the brazing costs in the manufacture of 500,000 door roll-backs.

Two unique methods of heating for brazing are reported in the *Welding Engineer*.[48] (1) the parts to be brazed inside a hydrogen bottle are heated to 1650° C by radiant heat and brazed, and (2) copper with preplaced brazing alloy is melted by resistance heat in molybdenum spot-welding electrodes.

Brazing Precipitation Hardenable Copper Alloys

The technique of brazing the alloys of Groups 7, 8 and 9 of Table 3 is no different from that employed in brazing the other seven groups of copper alloys. However, the cleaning of the surfaces and the fluxing of same must be done with greater care in order to forestall oxidation of the metal in the heating-up stage before the brazing flux or the brazing alloy melts and flows into place.

The fluxes made up of fused borax (with additions of a fluoride for the lower melting solders) mixed into a thin paste are usually satisfactory. Powdered brazing alloy mixed with the flux provides a coating of the solder the instant its melting point is reached. Once the faying surfaces are coated with the brazing alloy, the danger of oxidization is largely eliminated.

Setapen and Warren[50] report successful silver-alloy brazing of beryllium copper without seriously affecting age (precipitation) hardenability. Richards,[20] in a much more extended investigation, starts with a chemical cleaning of the metal using first 20% sulfuric acid at 150° F until black scale is off. Rinse, bright dip in 25% nitric acid 15 to 30 sec. Rinse in hot water and dry. Then clean mechanically immediately before fluxing for the brazing operation. Should use the BAg-la solder or silver-copper eutectic alloy and braze as quickly as possible in order to retain a good share of the 600° F precipitation hardenability. Generally speaking, the brazing should be done *after* the solution heat and quench and *before* the precipitation hardening heat.

Brazing with Silver-Phosphorus-Copper and Phosphorus-Copper

These high phosphorus, copper-silver and copper alloys have their largest field of usefulness in the brazing of copper and the high copper brasses having 15% or less of zinc, Groups 1 and 2 only of Table 3.

One advantage in using these alloys is that the phosphorus in the brazing alloy will deoxidize copper on which it is melted, causing exceptionally good surface alloying with it. These phosphorus-bearing brazing alloys will not creep into the area between overlapping surfaces as will either the soft solders or the silver solders (or indeed, the bronze brazing alloys). Hence, more attention must be given to the fillet at the edge of the braze than is necessary for soft solder or silver solder.

The phosphorus-copper brazing alloys have two further limitations which must be observed (1) The brazing alloy should not be used on steel and (2) its low ductility rules it out of a joint that is subject to impact or bending stresses. With the above limitations considered, these alloys become valuable aids in joining copper.

Joining Copper Bus Bars

An unusually complete study was made by Goeller[51] on the brazing of 6- x ½-in. bus bars assembled to carry 36,000 amp. An overlap of 1½ in. with a sheet of 0.010-in. BCuP-4 alloy in the joint, clamped and heated with a torch, made perfect electrical contact and adequate strength.

Bessesen[52] used copper-phosphorus alloy in a rather unique manner in a braze butt weld with the carbon arc in ¼- x 4-in. copper bus bars at the Wilson Dam. In four years' service, no trouble was experienced in heating of the joint, or in its mechanical strength.

The reviewer suggests that a copper welding rod with the inert-gas arc would make a more satisfactory butt joint. Falgner[53] gives a rather complete survey of the silver soldering of pipe, copper bus bars, tungsten carbide tools, etc.

A rather complimentary view of silver soldering was published by Clason[54] in describing the silver-brazed plumbing in the Lustron packaged homes. With a free choice to select any type of connection, the designers selected silver brazing as offering the most convenient, the strongest, most ductile, most corrosion-resisting joint available for copper tube plumbing installations.

BRAZING

BRAZING AT TEMPERATURES OF 871° C (1600° F) to 954° C (1750° F).

The Welding Handbook[2] describes a braze as being the use of a nonferrous filler metal having a melting point above 427° C (800° F) on base metals having melting points well above that of the given filler metal. This definition includes silver brazing which has been treated separately above. We restrict the unmodified term "Brazing" to a much narrower temperature range following commercial practice in this respect. Braze welding, formerly called "Bronze Welding," is the use of the bronze filler metal in an open vee or fillet rather than its being drawn between overlapping surfaces by capillary attraction, as is soft solder and silver solder.

In this review, we take cognizance of practical classifications leaving gaps in the temperature scale which have little real meaning. For example, in using copper tubing for plumbing, the designer has a free choice as to whether he shall employ soft soldering, silver soldering, phosphorus copper or yellow bronze brazing. Each has its advantages and disadvantages, but the installation should give equally good service whichever process is used.

The Welding Handbook[2] gives a very complete listing of the brazing processes, the various filler metals with many compositions of same and appropriate base meals. This is too long to introduce here. Instead, the much shorter table of copper-alloy brazing metals given by Imperati[7] is reproduced in Table 6.

These braze welding rods are usable in most applications as hard solders which (1) will be drawn by capillary attraction into a joint which has overlapping surfaces, and (2) also as a filler metal in an open vee or as a fillet with ample strength to transfer stresses across the joint. The designer should take advantage of the distribution of the bronze in the joint as (1) above or (2) above or wherever possible, both as a hard solder and as a strong fillet or filler metal. Soft solders can rarely be used as in (2) above, because of their weakness to tensile stress. Silver solders are rarely used as in (2) above, because of the high cost, roughly 20 times that of the bronze, and because they are not as strong in direct tension.

Braze-Welding Field

Though the temperature range, 1600 to 1750° F, noted in Table 1 and above, is rather narrow, the process itself is one of the most versatile of all of the joining processes. Applicable to all of the copper alloys of Table 3 with the exception of Groups 8 and 9, it is also applicable to nearly all nickel alloys and nearly all cast irons and steels. It is not employed on the aluminum, magnesium, titanium or the white metal die-casting alloys. It is an invaluable repair or maintenance tool. At the same time, it has many advantages as a production tool, particularly in industries based on sheet steel, as the metal furniture industry.

The reasons for this widespread use

TABLE 6—REPRESENTATIVE COPPER-ALLOY BRAZING METALS*

Mark or name	Melting temp., °C	Approx. compn., %	Remarks
Spelter solders	882 (1620° F)	50 copper 50 zinc†	Yellow bronze in lump, granulated or finely powdered form.
Naval brass, Tobin Bronze, etc.	885 (1625° F)	57 copper 0.50 tin Remainder zinc	Free-flowing, yellow-bronze welding rod.
Manganese and low-fuming bronzes‡	871 (1600° F)	56 copper 0.85 tin plus iron, silicon, manganese Remainder zinc	Low-fuming, yellow-bronze welding rod, having high strength in braze welding.
Nickel bronze	921 (1690° F)	48 copper 10 nickel 0.10 silicon Trace of phosphorus Remainder zinc	Low-fuming, high-strength, white-bronze welding rod.

*Other copper alloys which melt at higher temperatures are also used for brazing e.g., pure copper melting at 1981° F, and cupro-nickels at still higher temperatures. These, however, are used on ferrous metals and are unsuited for use on the copper-alloy base metals of Table 3.

†Part of the copper or zinc may be replaced by tin to reduce the melting point to 1495° F, or by nickel to obtain a white metal.

‡A small fractional percentage of silicon in the welding rod helps to keep down the zinc vapor. Hence, the name "low-fuming" for such rods.

involve the properties of the bronze alloy itself as: (1) the ready surface-alloyability of the molten bronze with the hot base metal, (2) the low yield point and high ductility of the hot solidified bronze which enables it to absorb shrinkage stresses without harm to itself or to the base metal, (3) the high strength and good ductility of the bronze filler metal after it is cold and (4) its good corrosion resistance as well as its good wear resistance.

In addition, the moderate temperatures employed in braze welding are, in most cases, harmless to the base metals occasioning little distortion. Moreover, there are many connections in which the braze weld is the most economical method of joining.

Brazing as a Repair Tool

Numerous examples in the literature bring out these points. The *Welding Engineer*[55] reports a successful repair to a 15-ton cast-iron rolling-mill frame using braze welding. Four hundred pounds of bronze welding rod were melted by the oxy-acetylene torch to restore the mill to operation. The saving in time and cost of a new casting made the job worth while. A similar cast-iron base, weighing 3 tons and belonging to a cold heading machine, was broken by loads of 125 tons repeated 70 times per minute. A braze- welded repair in 8 hr at a cost of $60 saved the $1100 cost of a new casting.[57]

Walker[56] gives an exposition on the use of the oxy-acetylene torch and bronze welding rods for keeping his

machinery in needed repairs. He comments on the economy in time, materials and over-all costs.

Keller[61] tells of the braze welding of a cast-iron column 8 x 10 in. in section, belonging to a shear frame. An oxy-acetylene torch, burning 870 cu ft each of oxygen and acetylene, heated the frame and melted 70 lb of manganese bronze filler rods in 7¾ hr to make the repair. Carter[62] reports the braze welding of an even heavier frame having 5½- x 9½-in. sections. Two welds were made in 20 hr, using 115 lb of high-strength bronze welding rods and the oxy-acetylene torch.

Yost[63] describes repairs to a heavy cast-iron crusher jaw which required 17 hr of welding time and 80 lb of ¼-in. bronze welding rod melted with the oxy-acetylene torch burning 920 cu ft each of oxygen and acetylene. He further describes the restoration of heavy bronze bushings by brazing.

Morton explains[58] how to determine the strength of a projected braze weld in cast iron by a very simple test. He uses the oxy-acetylene torch to heat the surface of the cast iron as in making a braze weld and builds up a pyramid of bronze thereon. He knocks off the pyramid with a sidewise blow from a heavy hammer. The bronze should pull out a deep piece of cast iron from the brazed area.

Wanamaker[60] writes of the procedure for the use of the oxy-acetylene torch and bronze welding rod (no composition) in repairing both light and heavy machinery. In all of these reports, the preparation of the surface for brazing is emphasized.

In railroad maintenance, Bennett[67] shows economies in resurfacing locomotive drive boxes with silicon copper rod used as a metal arc electrode. His article is complete with cost and wear records. Longo,[68] on the other hand, reports good success with phosphor bronze to build up worn locomotive surfaces. Another type of 7/16-in. diam cast bronze filler rod, having 77% copper, 8% tin, 15% lead, 0.45% phosphorus, was deposited by Holwill[69] with 1-in. diam carbon arc electrode carrying 700 amp. Kenefic[72] gives a still more complete description of their method of building up new and worn surfaces on locomotives.

Brazing as a Production Tool

The braze weld is used in the manufacture of a wide variety of products joining steel sheet metal, copper alloys, dissimilar materials as steel and a copper alloy, cast iron and steel and other combinations.

In some cases a nonsparking copper alloy is joined to a steel shank by braze welding. Graham[64] tells of joining brass tools to steel rod shanks by this method. In another instance, he describes the lengthening of an electric motor shaft by braze welding. In still another case, he describes the manufacture of a bronze cylinder by joining the halves by a temporary braze for purposes of machining.

Steel anchor lugs were braze welded to cast-iron water pipe[65] to take longitudinal tension bolts across the leaded bell and spigot joints. The shearing strength in the throat of the bronze fillet welds was 46,000 psi or 20,000 psi shearing strength of the bonding plane, bronze to cast iron. The cost was $6.00 per anchor. The brazing heat damaged the cement pipe lining only slightly.

In the manufacture and maintenance of laundry machinery, braze welding, as described by Jones,[66] improved the life of the Monel metal launders and reduced wash-wear on clothes.

Ayers[70] gives an extended discussion of applications of brazing to the manufacture of products from light gage

TABLE 7—COPPER AND COPPER ALLOY WELDING RODS AND ARC WELDING ELECTRODES

Common name	AWS-ASTM classification	Nominal (desired) composition, %					
		Copper	Zinc	Tin	Manganese	Silicon	Phosphorus	Nickel
Copper	ERCu	98. min (includes silver)	...	1.0	0.5	0.5	0.15	...
							Iron	
Copper-silicon (silicon bronze)	ERCuSi-A, RCuSi-B	94. min	1.5	1.5	1.5	2.8-4.0	0.5	...
		97. min	1.5	1.5	1.5	1.0-2.0	0.5	...
							Phosphorus	
Copper-tin (phosphor bronze)	RCuSn	94. min	...	4.0-6.0	...	...	0.20-0.30	...
	ECuSn-A	Rem.	...	4.8-5.8	...	...	0.15-0.35	...
	ECuSn-C	Rem.	...	7.0-9.0	...	...	0.35	...
							Iron	
Copper-nickel	RCuNi	67. min	1.0	1.2	1.25	0.10-0.50	0.6	29-33
Copper-nickel	RCuNi	Rem.	...	...	1.0	0.50	0.4-0.7	29 min
Copper-zinc								
Naval brass	RCuZnA (BCuZn2)	57. min	Rem.	0.25-1.0	...	...	...	...
Manganese bronze	RuCuZnB	56. min	Rem.	0.5 -1.0	0.01-0.50	...	0.25-1.0	0.5
Low-fuming bronze	RCuZnC	56. min	Rem.	0.75-1.10	0.01-0.50	0.04-0.25	0.25-1.25	1.0
							Phosphorus	
Nickel bronze	RCuZnD	45. min	Rem.	...	...	0.04-0.25	0.25	9-11
							Iron	Aluminum
Aluminum bronze	ERCuAl-Al	Rem.	0.02	...	...	0.1	...	6.-9.
	ERCuAl-A2	Rem.	0.02	...	...	0.1	1.5	9-11
	ERCuAl-B	Rem.	0.02	...	...	0.1	3.0-4.25	11-12

The "R" classification indicates copper and copper-alloy welding rods for use as filler metal with oxy-acetylene, carbon-arc and inert-gas (nonconsumable electrode) welding processes. The "E" classification indicates covered and bare copper and copper alloy electrodes for use with the shielded metal-arc and inert-gas metal arc (consumable electrode) welding processes.

Single values in this table indicate maximum percentages except where otherwise stated.

metals, while Hawley[71] discusses automatic applications of the oxy-acetylene torch in brazing.

Spraragen and Rosenthal[73] in a very complete review of the literature to January 1944 (foreign literature to January 1941) on the welding of dissimilar metals, present an illuminating discussion in Parts III and IV of brazing and welding of copper alloys, one to another, and to ferrous metals. Too long to be quoted in detail here, one is recommended to look up this reference when investigating the problem of a connection between dissimilar metals.

Perhaps the most important recent development in brazing has been the use of a volatile flux drawn in through the acetylene line. This has been especially valuable in the manufacture of metal furniture and other products made up of sheet metal, torch brazed. Its value lies in (1) the elimination of flux dipping of the rod and stopping to coat the base metal with flux, and in (2) the elimination of the troublesome flux glass which clings to the finished braze, making an expensive cleaning operation before the work can be painted. The vapor flux is drawn into the gas line and blown through the flaming nozzle in sufficient quantity to flux the base metal and the bronze. However, the residue of flux on the finished braze is so thin that it is cleaned off readily and does not interfere with the painting of the base metal.

Swift[74] shows that, with oxy-acetylene torch and fluxing equipment costing only $250, metal furniture may be assembled and brazed in a production line. He calls attention to the fact that "there is no flash or weld spatter to worry about; the flame-fluxing leaves no heavy beads of borax glass to be removed; the low temperatures required for braze welding minimizes distortion; the low fuming bronze shows a weld strength on steel of 55,000 to 65,000 psi; exact fit-up is not required as the bronze will fill up gaps."

Swift and Brown[75] comment on production jobs of various sorts using braze welding to join sheet steel in the manufacture of furniture, lawn mowers and other equipment made of sheet steel and tubing. They illustrate one application in which two oxy-acetylene torches, flame fluxers, low fuming bronze welding wire feeder work together automatically to make 15 in. of fillet welds per minute. Another advantage cited is that the brazing may be done in any position.

Similarly, Raffone[85] discusses the joining of sheet steel and steel shapes to make a variety of beds, chairs, desks, etc., by spot welding, arc welding and gas welding with emphasis on the last named method, using flux in the acetylene line and low-fuming bronze welding rod. He remarks that the use of the gas-fluxer eliminates an expensive cleaning operation as a preliminary to painting.

Maynard[86] reports a unique welding job he did on a 1400-lb bronze bell which had cracked in service. The bronze, 82% copper plus 18% tin, was preheated to 600° F, metal arc welded (probably with phosphor bronze electrode) at 275 amp and cooled slowly. Returned to the church tower, the tone of the bell was found to be restored, and it could be heard at a distance of three miles.

Brazing in the automobile industry is discussed by Jacobs[76] who finds that with the oxy-acetylene torch and gas fluxer such results are secured as: (1) fast operation, eliminating postbrazing cleaning, (2) a lower temperature than fusion welding in automobile repairs, (3) reduced distortion, (4) applicable to any position and (5) savings up to 40%.

Brazing of Pipe and Tubes

Brazing is applicable to both ferrous and nonferrous pipes and tubes. Kilburn[79] tells of numerous plumbing installations made in England by braze welding. Since the bronze has ample strength, better than 50,000 psi for the low-fuming bronze, to carry stress across a connection, recessed fittings are not absolutely necessary as in soft soldering or silver brazing. And poor fit-up can be bridged if need be.

The bronze can be applied to connections in copper tubing, red brass pipe, galvanized iron pipe and cast-iron pipe. The strength of the joint in cold drawn copper tubing will be that of light annealed copper adjacent to the joint, the bronze filler metal being much stronger. The corrosion resistance generally is good. In the case of bronze-welded, cast-iron pipe buried in the ground, the iron becomes anodic to the bronze but, owing to its large area compared to that of the bronze weld metal, the electrolytic wastage of the iron is very slight. Moreover, the cathodic bronze develops a film which further resists electrolytic currents. Spraragen and Chiswik[80] published in 1942 a searching review of the literature on the corrosion resistance of welded joints, with brief mention of welds in the copper alloys having generally satisfactory performance.

Brazing Galvanized Steel

In addition to the joining of plain sheet steel for a thousand and one objects which are to be protected by further operations, as phosphate dip, painting, plating, enameling, etc., a large tonnage of steel sheet and ferrous castings are protected by galvanizing in the steel mill, foundry or factory.

In making connections on such material by brazing methods, the low-fuming bronze and the oxy-acetylene torch with or without volatile flux through the gas line has been used. As explained by Galbraith,[98] when properly done with a narrow flame and rapid action, little, if any, of the zinc is evaporated along the joint.

However, the literature shows quite a few examples of the use of the carbon arc and a copper-silicon alloy as the added metal. Eckberg and Gaylord[99] take the further precaution of coating the silicon bronze with tin. By the carbon arc method, a sharply pointed carbon is used with the arc held strictly on the silicon bronze weld metal. The steel is not fused. The connection is, in effect, a braze. Tuft[101] used the carbon arc and Everduer silicon bronze to manufacture small ship models of steel in thicknesses from 0.066 to 0.105 in. for test in the Taylor Model Basin. He remarks that such "brazes" had satisfactory strength and ductility and were easier to make, though somewhat inferior in strength, to helium protected, metal-arc steel fusion welds.

Simkins[100] had a still different approach to the problem of connecting galvanized steel. In this case, the steel was No. 11 gage galvanized used to make a 36-in. diam foundry ventilator stack. He used shielded, aluminum bronze metal arc electrodes.

Brazing, Braze Welding, Conclusions

Judging from the numerous references in the literature, brazing, including braze welding, is a very versatile process adaptable to sheet metal and tubing as thin as 0.015 in. thick and to sections in cast iron or steel as large as 50 sq in. or more.

Surfaces to be brazed should be clean, free from graphite, grease and dirt. Borax base fluxes are commonly used. Vapor flux introduced through the acetylene or fuel line (never through the oxygen line) dissolved in water-free alcohol, or methyl borate, is used. Vapor flux is satisfactory for thin sheet steel, but for heavy sections additional flux will be needed.

Advantage should be taken of capillary attraction wherever possible to draw the molten bronze between overlapping surfaces. Maximum strength, with a minimum amount of bronze, is thereby obtained.

Bronze surfaces offer good corrosion resistance and good wear resistance and can be applied by the oxy-acetylene torch, the carbon arc, the metal arc and the inert gas arc.

COPPER-HYDROGEN BRAZING

1094° C (2000° F) to 1149° C (2100° F).

There are in the literature numerous references to the furnace brazing of steel in an atmosphere containing a desired 40% or more of hydrogen. Oxygen or air is, of course, excluded from the furnace atmosphere, as they make explosive mixtures with hydrogen. This joining process is in a narrow temperature range well above the liquidus temperature of copper and most copper alloys, and well below the solidus temperature of cast iron and steel. It is given separate mention because of its unique position in the temperature scale and because of its important commercial applications.

Jevons[88] has an historical approach to copper-hydrogen brazing, citing the early British Patent 5232/1910 granted to A. C. Hyde of Wolverhampton in 1910. The process was slow in getting started, using a hydrogen atmosphere in a high-temperature, 2050° F, furnace partly because of the slowness in securing a satisfactory furnace and partly because of the explosion hazard of hydrogen and air (oxygen). The first industrial use of the process was in 1933.

Steel may be heat treated or vitreous enameled *after* being copper-hydrogen brazed. This is not possible after silver brazing or after brazing with the yellow or white bronzes.

C. Rhyne, Jr.,[81] reports a very complete investigation into the strength of copper-hydrogen brazed joints in SAE 1010 and 4130 steels for aircraft applications. Effects of (1) area of bond; (2) finish of surfaces, (3) clearances between mating members; (4) protective (brazing) atmospheres; (5) time of brazing; (6) parent metal; (7) heat treatment after brazing; (8) contamination of brazing; (9) diameter and thickness of tubular members; (10) misalignment of members.

The joints were brazed with copper wire at 2050° F in a reducing, dry, gas atmosphere free of CO_2, heating-to-cooling below oxidizing temperature. The individual effect of the above variables is shown in 14 tables too long to be reproduced here. Excellent graphical representations and photomicrographs are given. An over-all summary indicates that (1) SAE steel tube joints, copper brazed, may be designed to fail at a stress above 30,000 psi for a wide range of finishes, clearances, fits, diameters and wall thicknesses; (2) that the yield strength of the parent metals have much influence on the strength of the joint. Thus, joints in 4130 steels can be designed for shear strengths of 25,000 psi minimum, whereas the softer (lower yield strength) of 1010 steels will develop joint strength of only 17,000 psi minimum unless the metal is made excessively thick.

Tylecote[82] made a somewhat similar investigation, finding a clearance of 0.002 in. for ½-in. rod and 0.005 in. for ¼-in. rod to be optimum, with time of brazing not critical. He found no improvement as a result of a solution heat treatment and aging.

An excellent discussion of the process is given in the Welding Handbook,[2] under "Furnace Brazing." Various types of atmospheres and methods of loading and unloading the furnace are described. Kelley[83] investigated copper-brazed joints in four steels having carbon 0.12 to 1.05% and found that the strength of the joint paralleled that of the parent metal as the latter property was varied by heat treatment. Kuhlmann[84] obtained generally good results in samples brazed in a continuous furnace using an atmosphere of dissociated city gas, different brazing times, fits, etc.

Peaslee and Boam[87] reported an unusually thorough investigation of brazed joints looking toward a braze that would withstand high service temperatures, in a turbine compressor, for example. Test specimens for testing in tension, shear, impact and penetration were brazed in an electric furnace usable up to 2300° F in an atmosphere of dry hydrogen gas having a dew point as low as −100° F. Used as brazing alloys were: (1) Oxygen-free copper, (2) 85% silver–15% manganese and (3) an alloy of composition 0.45 carbon, 4.50 silicon, 15% chromium, 4.00% iron, 3.75% boron, and 72.30 nickel. The base metal was AMS steel No. 5770 (0.45 C, 1.50 Mn, 0.65 Si, 20.0 Cr, 20.0 Co, 4.0 Mo, 4.0 W, 4.0 Cb, remainder Fe). They note difficulty in copper-brazing steels having more than 0.5% chromium or which are high in aluminum or titanium in a dry hydrogen atmosphere.

As a result of their searching tests, they reject the copper and the silver-manganese brazing alloys for service temperatures above 800° F, at which temperature butt tensile tests efficiencies are, respectively, 61 and 37%. The brazing alloy of (3) above, on the other hand, starts with an efficiency of 90% at room temperature and has 100% efficiency at all temperatures above 1500° F, being as satisfactory as the unbrazed base metal at 2000° F.

This last is surprising, as it has a solidus temperature of only 1850° F. The investigators explain this anomoly by saying that this brazing alloy and the No. 5770 are mutually soluble. Hence, the brazing alloy has diffused into the base metal at the brazing temperature of 2150° F. This fact inhibits penetration of the brazing alloy to the same extent that copper will penetrate. It also explains the high temperature head used for speedy brazing. Acrylic resin is a suitable binder for holding the powdered brazing alloy of (3) above in place with no interaction with the metals or the dry hydrogen.

Perhaps the near ultimate in copper-hydrogen brazing is detailed by Giroux[89] in which 120 different, variously shaped parts of steel weighing a total of 14½ lb are assembled and copper-hydrogen brazed to make a four-cylinder engine block for a light automobile.

FUSION WELDING OF COPPER AND COPPER ALLOYS

General. Fusion welding of copper and copper-alloy base metals must, of course, be accomplished at temperatures above the liquidus or within the range 885° C (1625° F) to 1261° C (2300° F). These are all nonpressure welds with the exception of resistance butt, spot, seam and stud welding. The common nonpressure fusion welding methods are oxy-acetylene, bare metal arc, shielded metal arc, inert gas metal arc, carbon arc. The inert gas metal arc for the copper alloys employs helium gas, argon gas or mixtures of these two gases. The process is further divided into (1) inert gas tungsten (nonconsumable) electrode metal arc,

or (2) inert gas, consumable copper alloy electrode metal arc. In designs where a connection is desired having the properties of the annealed base metal, a filler material is generally available.

Chapter 34 of the Welding Handbook [2] gives an excellent survey of welding methods for the copper alloys as they were available in 1949.

A. N. Kugler in Chapter 32 of the ACS Monograph "Copper"[90] brings us up to date, January 1954, with welding processes and applications summarized from 17 references.

The above two references are too long to review in detail here. The designer should, however, refer to them when in doubt as to a particular application. The various fusion welding processes will be discussed briefly below as they apply to each group from Table 3.

The *oxy-acetylene* is the oldest established method of fusion welding copper. The Review of 1936 cites the fusion welding of copper as early as 1912, 1915, 1917, 1927 and others. The oxy-acetylene process is still used and improvements have been made since 1936. The following citations will illustrate the fact.

As will be noted from Table 3: *(a)* the oxygen-bearing tough pitch copper is in one class as regards fusion welding, while the *(b)* oxygen-free or deoxidized copper is in another class. This distinction is brought out repeatedly in the literature,[3, 11, 90] and in numerous other places. It is very important in oxy-acetylene fusion welding operations (though not at all important in soft soldering, silver soldering and not too important in brazing).

C. E. Swift and the writer[91] in an extended research on the welding of tough pitch and deoxidized copper, found a decided preference for the latter, as did Vreeland.[92] Cook and Davis,[93] in a comprehensive investigation, were equally sure that phosphorus - deoxidized-copper base metal was more weldable than tough pitch copper in both the arsenical (0.40% arsenic in base metal only) and non-arsenical grades. They used the 1% silver-copper welding rod. Benefits from the substitution of phosphorus-deoxidized (phosphorus 0.05 to 0.10%) base metal for the oxygen-bearing base metal were improved weldability, strength and soundness in the welded seams of ¼- and 9/16-in. thick copper plate. They noted also that either arsenic or phosphorus would raise the annealing temperature of copper.

Young[94] also concluded that the deoxidized copper was more weldable than oxygen-bearing copper, though, in his investigation, the carbon arc and phosphor bronze welding rod was used and not the acetylene torch, as was the case with the other researchers.

The objection to the use of oxygen-bearing tough pitch copper has been explained many times. The free hydrogen atoms in a gas flame will penetrate several thousandths of an inch below the surface of red hot copper to react with cuprous oxide present in the copper to form steam. This high pressure steam makes surface cracks in the heat-weakened copper. West[11] gives an excellent exposition of this reaction with photomicrographs of the damaged copper. The filler rod for deoxidized copper base metal should also be deoxidized to improve the soundness of the weld metal.

An extensive research in the laboratory of The American Brass Co. resulted in the development of a proprietary alloy containing tin, and deoxidized with silicon and manganese.[95] This filler rod developed originally for the oxy-acetylene and the carbon arc processes has also found

widespread acceptance for use in inert-gas-shielded arc.

This (ERCu) and other filler rods are tabulated in Table 7, which is abstracted from the tentative specifications for copper and copper alloy filler rods and electrodes issued jointly by the American Society for Testing Materials and the American Welding Society.[42]

Important Similarity and Distinction

It may be observed that the "R" welding rods in the copper-zinc classification of Table 7 are identical with the last three alloys of Table 6. The reason for this is rather important: The rods of Table 6 and the "R Copper-Zinc" rods of Table 7 are *brazing* metals for all of the copper alloys in Table 3 including 85/15 red brass and other brasses having less than 15% zinc. But for brasses having 30 to 42% of zinc, they are *fusion* welding rods and are unsatisfactory as brazing rods. The high zinc brasses, naval brass, Muntz metal and manganese bronze used as base metals should be melted simultaneously with the addition of the filler metal.

In selecting an appropriate welding rod from Table 7 to use on a base metal of Table 3, the normal procedure would be to select a rod of the composition which is nearest to that of the base metal. However, this does not in all cases bar the use of a different rod, electrode or welding process.

While the oxy-acetylene torch is the oldest method of welding copper, it has been largely superseded by the inert-gas arc. These newer methods are less likely to have hydrogen in the flame, so that the tough pitch copper is not likely to be as severely embrittled as it would be in an oxy-acetylene or oxy-hydrogen flame. And the intense concentration of heat in the arc enables the operator to make a pass so quickly that there is a minimum opportunity for the cuprous oxide-copper eutectic to collect at the grain boundaries.

This fact led Chyle[96] to suggest that electrolytic tough pitch (oxygen-bearing) copper may be used in copper weldments as an equivalent of deoxidized copper.

However, most authorities do not agree. They have found that the better weldability and greater reliability of the phosphorus deoxidized copper makes the latter preferable for such important copper weldments as pressure vessels, chemical equipment, etc.[92-94, 97, 7]

Chyle[96] reported, in the 1951 Adams lecture, a very thorough investigation in the welding of copper as a preliminary to the manufacture of reactors which were lined with welded copper plate ½ in. thick. Some of the more pointed conclusions reported in this lecture are:

1. The pure tungsten (nonconsumable) electrode is preferred to the thoriated-tungsten electrode for the inert-gas welding of copper. The latter results in deep undercutting of the parent metal.

2. Helium was preferred to argon as the shielding gas. The higher voltage required in the arc with helium and its higher specific heat as compared to argon are cited as advantages.

3. Direct current with tungsten electrode negative (straight polarity) is preferred to alternating current or direct current with reversed polarity.

4. Tough pitch copper, phosphorous deoxidized copper, and OFHC copper are ruled out as filler rods, while those having tin, silver and/or silicon are acceptable, having weld strengths and ductilities comparable to the tough pitch and deoxidized copper base metal. These rods would have com-

positions within the limits of ERCu of Table 7.

In the above method of arc welding, helium or argon gas-shielded, nonconsumable, tungsten electrode, the electrode must be an appropriate size for the thickness of the base metal and the size of the filler rod. The nozzle must be cooled, preferably by water, and a reasonable amount of skill exercised by the operator.

A still newer method of using inert-gas shielding is with a *consumable electrode* fed automatically into the arc as it is melted. Several different designs of the apparatus are described in the literature. Muller, Gibson and Roper[102] announced the use of an automatic travel head and an automatic hand nozzle for feeding a flexible wire electrode through the helium or argon protective gas into the arc which springs from the melting wire to the base metal, which is melted at the same time. In a series of 12 references, they trace the development of the process from the work of G. E. Doan[103] and others from 1936 on.

Muller and associates[102] remark that the process is basically sound as it is not complicated by fluxes, slags, chemical reactions or gas molecular changes, while the arc in reversed polarity effectively removes the surface oxide film from the crater. Moreover, the metal transfer is very efficient with the exception of brass wire which loses some zinc by evaporation in the arc.

One important point they bring out is that above a certain minimum current density, which varies with both size and material of the electrode, "the transfer through the arc changes from large globular drops with erratic action of the arc and considerable spatter to a spray of extremely fine droplets, which are projected from the end of the electrode in the direction in which it is pointed." This point was investigated further by Muller, Greene and Rothchild[108] who noted a "stiffness" in the metal spray at high current densities giving it excellent directional control and enabling the operator to weld in any position.

Robinson and Cook[109] report an important advance in the inert-gas consumable metal electrode process in the use of stranded electrodes where the strands are different metals. As is well known, it is commercially impracticable to make certain alloys into wire, e.g., it would be virtually impossible to draw 85 copper–15 tin into wire, while 85 copper–15 zinc draws readily into very fine wire. On the other hand, most elementary metals are ductile. Hence, any desired weld deposit may be made by stranding together wires of the elements or alloys having the needed areas to yield the desired proportions. As a practical result, the elements in the different wires in the high temperature of the arc and in the extremely small droplets attain a state of homogeneity in the weld metal better than that of a casting having the same composition.

Robinson and also Lewis and Stirn[110] patented composite stranded or wrapped electrodes which would give a deposit by the shielded metal arc method of a desired composition such as could not be obtained in a single commercial rod or wire.

For the copper alloys, the minimum current density for the fine spray is rather high, being of the order of 100,000 amp per square inch. Hence, small diameter electrodes around 1/16 in. are used for the most part. In turn, this means a high burn-off rate of the order of 20 fpm. Hence, even though the arc voltage is held constant automatically, the element of skill is involved—especially in a manually held nozzle. However, excellent results in terms of weld metal quality in the cop-

per alloys is reported by the above and others.

Conway[104] calls attention to the patent of H. M. Hobart in the early 1930's on the use of helium for welding. The hotter arc of a given length in helium over that in argon is due to the fact that the voltage across the arc in the former is 40% higher than in the latter. The energy is proportional to the voltage for a given current.

Robinson and Berryman[105] give a further and more complete investigation of the use of the inert-gas, consumable-electrode metal-arc process in welding ten copper alloys in thicknesses from ⅜ to 1½ in. Electrode wires of aluminum bronze, silicon bronze, phosphor bronze and deoxidized copper yielded welds of good commercial strength, ductilitv and soundness without exceptional skill on the part of the operator.

Yaczko[106] explains commercial applications of the process calling attention to difficulties in joining Everdur to steel (cracking in the weld crater). Deposits made with aluminum bronze electrode wire were less likely to crack.

Rockefeller and Herbst[107] explain a welding process using the inert-gas arc and the consumable electrode automatically fed into the arc. Rockefeller calls attention to the fact that "The use of inert gas has become a major welding process in less than a decade, i.e., 1941 to 1951. And it has not only largely replaced other methods, but has permited fabrications hitherto impracticable for welding."

Rockefeller[107] notes that alternating current is preferred for welding aluminum, magnesium and aluminum bronze with the tungsten electrode, and direct current for all other metals. He calls attention to several benefits from the use of the inert-gas consumable electrode process, thus:

1. Eliminates flux and resulting slag. Particularly important in welding aluminum and magnesium since most of the fluxes used therewith are corrosive.

2. Characteristically higher current densities—yielding deep penetration, narrow welds, smaller heat-affected zones and reduced distortion.

3. Rapid deposition results in reduced costs.

Wooding[111] gives an excellent survey of the inert-gas, metal-arc process with an historical approach, illustrated by a picture of a welding shop of 1887 in which the carbon arc and battery current was being used, DeBernardos having invented the carbon arc in the 1860's, while Slavianoff tried the metal arc shortly thereafter using a bare metal electrode with indifferent success. Kjellberg of Sweden coated the metal electrodes (time not stated).

Wooding[111] also reports L. J. Weber as having in 1926 tried welding in helium atmosphere reporting his work in *Trans. Am. Soc. for Steel Treating*, XI (1) 1927. He also notes that high current densities of 40,000 to 70,000 amp per square inch are needed for stable metal arc in inert-gas atmosphere with electrode positive. His work was done mostly on aluminum.

The Welding Journal[112] reports the welding of 1-in. thick copper at Ansonia Copper and Iron Works with deoxidized copper consumable electrodes 1/16 in. diameter using 470 amperes, 157,000 amperes per square inch, reversed polarity, in helium-argon gas. The burn-off rate was 33 feet per minute with 5 passes needed, including the root pass, to weld the 1-in. thick metal.

The Welding Journal[113] reports another interesting job where a high-speed tubing machine built by the Yoder Co. for the Bridgeport Brass Co. heats the abutting edges by induction

and proximity effect to make the longitudinal fusion weld in copper alloy skelp in thicknesses from 0.025 to 0.134 in.

Jewell[114] describes the first welding of large copper tanks by the use of the inert-gas, shielded, tungsten arc with straight polarity. He used ¼-in. diam copper-silicon-manganese filler rod. As a result of this work, he recommended: (1) That welding be done in cooler weather to reduce operator fatigue—welding in this case was done at 115° F temperature and 95% humidity; (2) and that there be cleanliness of metals and site.

The welding of rotor bars of copper alloy to copper end rings in the manufacture of alternating-current electric motors is described by Huff.[115] An automatic inert-arc process is used to fuse the parts together making a strong and electrically efficient joint.

Another method of welding, in this case the carbon arc, is used to weld the armature wires to the copper commutator bars in the manufacture of 3- to 5-hp direct-current electric motors in which there are 65 connections.[116] A water spray protected the insulation from the welding heat. A copper tank, 8 ft in diameter by 18 ft long, made of 3/16-in. copper sheet with ¼-in. thick copper heads was welded satisfactorily with the argon-shielded arc.[117]

All of the ten groups of copper alloys of Table 3 may be welded by one or the other of the inert-gas, arc-welding processes. However, the copper-zinc alloys — brasses and bronzes — of Groups 3 and 4 are prone to lose zinc by evaporation in the high temperature of the arc. Fuming of zinc is troublesome and must be kept to a minimum.

Cadmium of the Group 10 bronze is also prone to evaporate in the high temperature of the arc. Cadmium vapor is toxic and extra precautions must be taken to avoid this hazard when cadmium-copper alloys are welded.[118]

Little work has been done in fusion welding high zinc alloys (as those of Groups 3 and 4 of Table 3) by the inert-gas-shielded arc. However, silicon bronze and aluminum bronze work quite well as consumable electrodes in the inert-gas-shielded arc and are much used therewith.

Walker[123] reports the welding of ¼- x 5/16-in. naval brass plate using the carbon arc and low-fuming bronze rod and silicon-copper rods.

Ronay[124] cautions against the locked up stress near the weld in naval evaporator shells 6 ft in diam by 6 ft long of 5/16-in. naval brass plate. In some cases it was as high as 9000 psi. He recommends a stress relief anneal at 750° F held for 1½ hr for each ½-in. of thickness and cooled slowly to avoid stress-corrosion cracking in service.

Schlosser[131] reports the welding of a heavy hydrolyzer made of 13/16-in. phosphor bronze, 96% copper–4% tin, using a bare phosphor bronze metal arc electrode. He had tried the carbon arc and the oxy-acetylene methods previously with poor success. With the metal arc, he obtained satisfactory welds having a strength of 39,000 psi. This was in 1941 before the inert-gas arc became well established. Sandberg[125] the next summer reported a similar welding job on a large, phosphor bronze pressure vessel attaining good results with a low-phosphorus bronze *covered* metal arc electrode.

Spencer[119] gives a rather comprehensive survey of various preferred methods of welding the copper alloys, citing 16 references. The articles are well worth consulting but are too long to be abstracted here.

Richards[20] gives a very complete dissertation on the joining of beryllium

copper, Group 9. For fusion welds he suggests the carbon arc or the inert-gas arc using either beryllium copper, Everdur, or aluminum bronze rod for filler metal.

Hawthorne[120] obtained excellent results in welding the 90/10 cupro-nickel using the inert-gas-shielded processes and the 90/10 cupro-nickel welding rod or electrode. Tensile strengths up to 50,000 psi with excellent ductility were obtained.

Aluminum bronze covered electrodes are available and are found useful in metal arc welding of aluminum bronze and other alloys. Garriott[121] reports a very complete series of tests made to conform to ASME Boiler Code Special Case No. 1108 published in *Mechanical Engineering* February 1950. Carbon arc, inert-gas arc with both tungsten and consumable electrodes and submerged arc processes were tried. Good results were obtained and recommendations made. Earlier tests were reported by Swift[49] on the use of these coated aluminum bronze electrodes in making deposits requiring a strong, hard, wear-resisting surface on various base metals. On steel this would be an arc braze rather than a fusion weld, the arc being kept on the filler metal.

Sandberg[125] explains the use of the metal arc and phosphor bronze-covered electrodes in the welding of heavy phosphor bronze plate. This was in 1942 before the inert-gas arc had been perfected for the copper alloys.

Generally speaking, all of the copper alloys of Table 3 may be fusion welded. However, not all processes are equally well adapted to all alloys. The selection of welding process and filler metal must be determined after considering the application in which the weldment is to be used.

Resistance Flash, Spot, Seam and Stud Welding

This is the only welding process in which the high electrical conductivity of copper occasions difficulties. In the interval since 1936, noteworthy progress has been made in this field. Some valuable research on resistance welding was done at Rensselaer Polytechnic Institute[126] under the direction of the late Dr. W. F. Hess. He remarked that Dr. Hotchkiss, President of Rensselaer Polytechnic Institute, had said in October 1937 that "The joining of metals, including welding, was still more of an art than a science." However, much was done under his direction to change this situation.

Much was done also by the resistance spot and seam welding machine designers and the designers of resistance flash and butt welding equipment as well. In particular, the use of stored energy in a magnetic coil or condenser bank gave an impetus to resistance spot and seam welders making them applicable to aluminum with a minimum energy supply. Mikhalapov and Weygandt[127] in 1940 made a careful theoretical evaluation of the stored-energy spot welders of the electro-magnetic field type, while Hilbert[128] explained the practical application of the condenser discharge type in spot welding aluminum.

Dawson and Wise[129] give a still more searching report of the stored energy systems. They mention L. W. Chubb and his percussion welding which was developed in the 1910-20 decade to make connections in incandescent lamp manufacture. Also patents of J. A. Heany in 1913 on electro-magnetic storage which was popularized in France by Sciaky and Languepin. The former introduced his machine into this country in 1938-39. Wood[130] a month earlier published an evaluation of the two types of stored-energy spot-welding machines.

While the primary objective of much of the spot welding equipment noted above was the spot welding of aluminum in the manufacture of aircraft, it did extend the use of such processes for the copper alloys as well. Wood, Babin, and Atkin[132] tested the efficiency of spot welds by the torsional shear method in the silicon red brass (77Cu–22Zn–1Si) which brass had been found useful in the manufacture of refrigerator evaporators by resistance spot and seam welding.

Both Taylor[134] and Gillett[135] emphasized the need for sensitivity in the pressure control of spot welds made at high speeds. They suggest the use of light weight in the moving spot welding electrode in order to reduce the inertia forces. Taylor reports the reduction of the moving electrode mass from 150 to 2 lb. He obtained copper-to-copper and copper-to-leaded-brass spot welds with the more sensitive welding head.

Brandt[133] discusses the machine variables and methods of control in flash welding needed to weld the nonferrous alloys. The controls of heating times, current values, voltage, holding pressure, push-up pressures and times are much more critical for the copper alloys than for steel.

"Poke" or Stud Welding

In making fastenings to a plate, in which it is expensive and undesirable to drill the plate, the structural member, the tank or other stator, a new method known as the "poke" weld is employed to weld studs thereto.

Herbst[136] in an early description of the inert-gas arc explains the use of this simpler equipment to spot weld liners to steel tanks in 4 sec per spot. He details applications involving pure silver, Monel, Everdur and other copper and nickel alloys. Pilia[137] describes an improved inert-gas welding head weighing only 2 lb which spot welds one sheet to another underlying it as in automotive work, refrigerator manufacture, etc.

Herbst also describes the welding of an 8 ft diam by 18 ft long tank made of 3/16-in. diam Everdur and ¼-in. thick heads. In this instance, alternating current was used. In later work the direct current was found preferable.

Brewster[138] cites the advantages of stud welding where studs ⅛ to ¾ in. diam are welded to steel, aluminum studs to aluminum plate, brass and Monel studs welded to a stator by the controlled cycle process. High-frequency pilot arc guides power arc stud to plate, flash of heat and then pressure completes the job in an automatic cycle. Arc times 0.15 to 0.50 sec with arc currents 150 to 500 amp. A suggested stud design is up to 3 times plate thickness.

A later development[139] is in a capacitor-operated stud welder which uses only 2 kva. With it one operator can place 3000 studs per hour with the air-operated, portable gun. Studs from 3/32 to ½ in. diam can be welded to thin sheet or heavy plate with a strength comparable to that of the heavy metal. Most combinations of metals are possible as, for instance, brass to zinc die casting.

WELDING GOES TO COLLEGE

The copper industry is indebted to the colleges and technical schools for many of the advances made in the art of welding copper. This is not surprising, as an industry having such wide ramifications as the welding industry must necessarily be given the attention of the educators. Such is indeed the

case. A vocational or technical school in any industrial community will almost invariably have a welding instructional department.

Professor Doan[103] did most of his work on the inert-gas arc at Lehigh University, while Professor Henry[141] used the facilities of Brooklyn Polytechnic Institute on important metallurgical studies of welds. Professor Harrelson[142] outlines the courses at Georgia Institute of Technology which orient welding to engineering, while Professor Schultz[143] does the same for Oklahoma A. and M. College. Professor Young[94] takes up welding at Michigan College of Mines and Technology.

Turnquist[144] published an excellent outline for the layout and instructional equipment for school welding shops. The outline is well worth studying.

Ohio State University is the first to confer the degree of Welding Engineer. Other schools are slow in following this lead, but none of them are slow in recognizing the importance of the welding industry. Usually some mention is made of welding metallurgy in one or more of half a dozen departments of instruction.

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HEAT TRANSFER CALCULATIONS BY NUMERICAL METHODS

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THE AUTHOR

Commander Dusinberre's first paper on heat transfer was published in this Journal in May, 1930. He has since made other contributions in that field, and is now a member of the executive committee of the Heat Transfer Division, ASME, and a Fellow of that society. Since retirement from the Navy he has taught at Virginia Polytechnic Institute and the University of Delaware and at the present time is professor of mechanical engineering at the Pennsylvania State University.

The average engineer, in his undergraduate studies, learns to calculate the steady flow of heat in flat slabs and hollow cylinders, and in simple types of heat exchangers. Perhaps also he may learn to use the Gurney-Lurie type of graph for calculating transients in simple geometrical shapes with simple imposed conditions.

But more difficult problems constantly arise in practice. The engineer with graduate training may have studied the admirable analytical theory which began with Fourier and led on to methods of contour integration and Laplace transforms for solving the partial differential equations of heat conduction. On mastering these methods the student is apt to say, "This is it! This is wonderful!" But the practical difficulty remains that the range of soluble problems is only slightly extended and the solutions, though they may be expressed in concise mathematical notation, are extremely difficult to evaluate.

Meanwhile, engineers have to produce designs, and to produce designs they have to make predictions. Furthermore, they have to make these predictions in the most economical way.

In the great majority of engineering problems, the most economical way to make predictions is by calculation. For example, we have well-tested strength formulas, deflection formulas, and heat-transfer formulas for the

simple cases. Sometimes the calculation is more involved, as in the Hardy Cross moment-distribution method for framed structures.

Sometimes experiment is necessary. In the extreme case we make a full-scale test of the completed design, and when not too much time and material are involved this may be the most economical way to do the job. Perhaps we can experiment on partial models or scale models, as in many stress-analysis studies. In heat-conduction studies, electrical models or analogs have often been used. In general, these methods are expensive.

The object of this paper is to show that a great many complex heat transfer problems can be solved by calculation, even though not tractable by conventional analytical methods. Thus, much costly experimentation can be saved.

The methods to be outlined are based on the use of finite space intervals and finite time steps. The mathematician, and unfortunately often the engineer with graduate training, will immediately cry, "Ah, but then you have merely an approximation!" We will grant the "approximation." Any engineering calculation is an approximation, as we well know. But we will not grant the "merely." For our object is not to solve differential equations as such, but to solve engineering problems. From this point of view an analytical solution is itself an approximation, since no engineering material is strictly the "homogeneous isotropic continuum" which the mathematician takes for granted.

The preceding paragraph sounds argumentative, and a few years ago this sort of argument was necessary. It is much less so today since industry has gone heavily for the use of digital computing machines. A calculus problem to be solved on these machines must in general be put in finite-difference form. Thus, essentially all that I argue here is that we should go to finite differences sooner rather than later. Then if the problem becomes unwieldy for manual calculation, we still have saved a lot of work in getting it ready for a machine calculation.

The first step in obtaining a numerical solution is to *subdivide the system*. Usually there are some points at which the temperatures are known, and others at which we wish to find the temperature. Some auxiliary points may also be needed. For example, consider a laminated slab in which heat is being generated, exposed to an ambient temperature on each side. We would probably want to know the surface temperatures, perhaps some of the interface temperatures, and perhaps a few more, sufficient to define the interior temperature distribution.

What do we mean here by "sufficient?" This is not a matter of mathematics but of engineering judgment, depending on how good our data is, and even more on what use is to be made of the solution after we get it. If we have some idea of what the answer will look like, that is helpful. But if we are working in the dark let us observe:

RULE 1. Start with the crudest possible subdivision. Even if the solution is evidently too crude, the results will be useful toward a more refined calculation.

If we are concerned with a transient problem, heat storage comes into the picture, and a certain amount of material is associated with each reference point.

In the case of a homogeneous slab the subdivisions might be as shown in Figure 1 (a) or (b). In each case the step "curves" might or might not define the temperature distribution with sufficient accuracy for the purpose at hand.

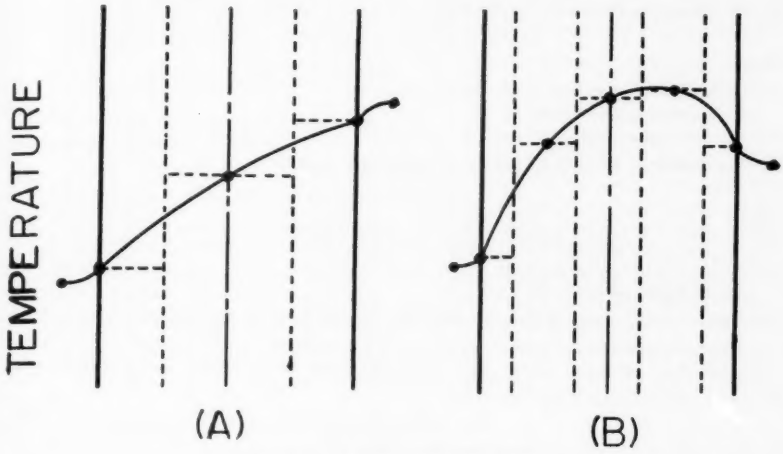

Figure 1. Subdivisions of a slab.

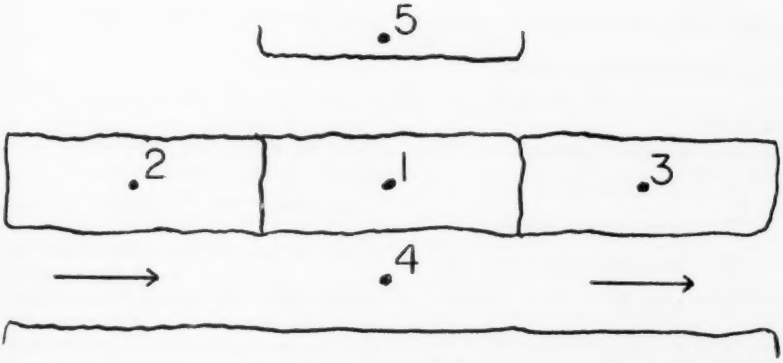

Figure 2. An irregular system.

For greater generality, let us consider a two-dimensional region and write down some typical equations that might arise. The boundaries in Figure 2 are purposely drawn as irregular, to indicate that no particular geometry is implied.

We are going to write equations for all the heat flow *to* Region 1. Region 2 can transmit heat by conduction. We write:

$$Q_{21} = K_{21}(t_2 - t_1) \text{ Btu/hr} \quad \ldots\ldots (1)$$

where:

Q = rate of heat flow, Btu/hr
K = conductance, Btu/hr °F
t = temperature, °F

The conductance term is found by an equation such as:

$$K = kA/L \quad \ldots\ldots (2)$$

where:

k = thermal conductivity, Btu/hr ft² (°F/ft)
A = mean area of path, ft²
L = length of path, ft

If t_1 happens to be higher than t_2, then the flow *to* Region 1 is negative.

A similar equation is written for the flow from Region 3 to Region 1.

Region 4 is assumed to be in an ambient fluid and transfer is by convection. We write the same form of equation:

$$Q_{41} = K_{41}(t_4 - t_1) \quad \ldots\ldots (3)$$

but here the conductance term has the form:

$$K = hA \quad \ldots\ldots (4)$$

where:

h = surface coefficient, Btu/hr ft² °F
A = area, ft²

Region 5 is assumed to be a surface exchanging heat by radiation. Again:

$$Q_{51} = K_{51}(t_5 - t_1) \quad \ldots\ldots (5)$$

Here the K term has the form:

$$K_{51} = \sigma F_e F_g (T_5^3 + T_5^2 T_1 + T_5 T_1^2 + T_1^3) A \quad \ldots\ldots (6)$$

in which:

σ = Stefan-Boltzmann constant

F_e = an emissivity factor

F_g = a geometrical factor

T = absolute temperature, °R

A = area, ft²

It may be noted at this point that k in Equation 2 and h in Equation 4 may be functions of the temperature, and the temperatures themselves enter directly in Equation 6. In a steady-state problem this may require successive approximations, and in a transient problem, occasional changes in the K's. Herein lies an advantage in following Rule 1; an approximate figure is quickly reached.

Equations 1–6 represent all the modes of heat transfer to a region by virtue of temperature differences. In addition, heat may be effectively generated within the region, independently of any temperature difference, by physical or chemical changes or mechanical or electrical effects. For endothermic phase changes or reactions this item will be negative. For any such quantity we may use the symbol Q_g.

Then the total effective rate of heat flow to Region 1 will be:

$$Q_1 = K_{21}(t_2 - t_1) + K_{31}(t_3 - t_1) + K_{41}(t_4 - t_1) + K_{51}(t_5 - t_1) + Q_{g1} \quad \ldots\ldots (7)$$

A similar equation can be written for each region in the system under study.

A concise notation is:

$$Q_n = \sum K_{mn}(t_m - t_n) + Q_{gn} \quad \ldots\ldots (8)$$

Now, if the system is in a steady state with respect to time,

$$Q_n = 0 \quad \ldots\ldots\ldots (9)$$

for all regions within the system. In this case we have a set of simultaneous linear algebraic equations which can be solved by any appropriate method. When the number of equations is few, the methods of elementary algebra are satisfactory. For a larger number, determinants may be used. Also for large numbers, a very good method is the "relaxation" procedure of Southwell.*

In the "transient" situation, temperatures are changing with respect to time. Here the principle of conservation of energy shows that the rate of heat storage within a region must equal the rate of heat flow into the region. Sometimes a latent heat exists and heat storage may take place without change of temperature; this will be discussed later. More generally, in an interval of time, $\Delta\tau$, the temperature will change from t to a different value, t'. Then we may write:

$$Q_n = C_c\,(t_n' - t_n)/\Delta\tau \text{ Btu/hr} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where:

C = Heat capacity of the region, Btu/°F
$\Delta\tau$ = a small finite time interval, hr
t = temperature at the beginning of the interval
t' = temperature at the end of the interval

In this equation:

$$C = \sum v\,\rho\,c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

where:

v = volume of any particular material in the region, ft^3
ρ = density of the material, lb/ft^3

8, a smiliar equation can be written for each region under consideration. It is and the summation is over all materials in the region. As in the case of Equation

c = specific heat of the material, Btu/lb °F

noted that c may be strictly a variable, just as k, h, etc.

Now we can eliminate Q_n between Equations 8 and 10:

$$\sum K_{mn}(t_m - t_n) + Q_{gn} = C_n\,(T_n' - t_n)/\Delta\tau \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Note that this equation applies to a region, n, and m is a general subscript for the regions in thermal contact. If we now use subscripts i, j, . . . for these external regions, we can expand and solve for t_n', thus:

$$t_n' = \frac{K_{in}\Delta\tau}{C_n} t_i + \frac{K_{jn}\Delta\tau}{C_n} t_j + \ldots\ldots$$

$$+ \left(1 - \frac{\sum K_{mn}\Delta\tau}{C_n}\right) t_n + \frac{Q_{gn}\Delta\tau}{C_n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

* This method will be taken up in a later paper.

This may be written more concisely:

$$t_n' = F_{in}t_i + F_{jn}t_j \ldots + F_{nn}t_n + G_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

where the F and G terms can be obtained from Equation 13. Note that the sum of the F terms is unity. Except for the effect of generated heat, each t′ is a weighted average of certain t's.

The group of equations of this type are the forms used in actual computation. If we intended to write differential equations we would let the size of the regions and the size of the time interval approach zero, but we do not do this. The same time interval is used in all equations, and the equations are applied iteratively over whatever period of time is necessary.

An important point is that the time interval, $\Delta\tau$, cannot be chosen entirely arbitrarily. Each F_{mn} is inherently positive, but if $\Delta\tau$ is sufficiently large F_{nn} will become negative. In this case the system of equations may become divergent, just as a series may diverge outside a particular range. Speaking in physical terms, a negative value for F_{nn} amounts to saying that the hotter the region is now, the colder it will be in the future. So we must observe: RULE 2.

$$1 - \frac{\sum \overline{K_{mn}\Delta\tau}}{C_n} \geqq 0$$

$$\text{or: } \Delta\tau = \frac{C_n}{\sum K_{mn}} \ldots\ldots\ldots (15)$$

This "convergence criterion" must be observed for each region in the system.*

The application of these equations is best illustrated by an example, and for this purpose we choose a problem which involves all three mechanisms of heat transfer: radiation, conduction and convection.

In figuring the load on a summer air-conditioning system, the wattage supplied to electric lights is ordinarily taken as a direct sensible-heat gain to the circulated air. Mr. Charles S. Leopold, an air-conditioning consultant, observed in practice that this led to over-design. The energy supplied went only in part to the air by convection, while a considerable fraction went directly to the floor and ceiling by radiation. (We consider, as Leopold did, an area near the center of a large room, so that the walls could be left out of account.) Of this fraction, part would be re-transferred to the air by convection but part would flow into the solid structure by conduction. If no heat were lost to the outside, an equilibrium would be reached so that all heat would be returned to the air and the design assumption would be valid. But with an office or store, in use 8 or 9 hours a day, this equilibrium might never be reached in the normal period of occupancy.

For the purpose of predicting this effect, Leopold truly remarked that conventional mathematics would be "complicated beyond reasonable engineering application." He therefore constructed an ingenious hydraulic analog which he described in a paper.†

* Various mathematical researches have indicated that in some cases this limitation may be exceeded. The author, however, has never found that the gain, if any, is worth the trouble of determining a new criterion.

On the other hand, G. Liebmann, in an important paper (A.S.M.E. Paper No. 55-SA-15), has shown that this type of convergence criterion can be avoided entirely by equating the heat storage rate to the heat flow rate at the *end* of the chosen time interval, rather than at the *beginning* as is done here. The approximation is equally valid. However, instead of an explicit equation for each t′, we get a set of simultaneous equations for all the t′'s. This is a disadvantage for manual solution and in most cases for digital computer solution. But Liebmann shows an electrical analog with which the solution becomes very convenient.

† C. S. Leopold, "Hydraulic Analog for the Solution of Problems of Thermal Storage, Radiation, Convection and Conduction," Heating, Piping and Air Conditionig, Vol. 20, No. 7, p. 105, July, 1948.

It happens, however, that this problem can be handled rather simply by finite-difference methods. The problem is a useful example because all modes of heat transfer are involved and because an alternative solution is available in the reference paper. We use the same assumptions that Leopold did, so far as these assumptions are stated in the paper and in the discussions thereon.

The system is taken as one square foot of floor and ceiling slab, with the intervening air and lighting arrangements. Other contributions to the cooling load are assumed to be handled in a separate calculation. A multi-story building is assumed, with identical operations on each story, so that the center of the ceiling slab duplicates conditions at the center of the floor slab.

The slabs are taken as 10 in. of cinder concrete with the following properties:

Density: 105 lb/ft^3
Specific heat: 0.18 Btu/lb °F
Conductivity: 4.9 Btu/hr ft^2 (°F/in.)

There is no furring, and steel work is ignored.

About the simplest subdivision (Rule 1) and one that proves to be adequate, is that shown in Figure 3. 2.5 in. of material is associated with the floor surface, F, 2.5 in. with the ceiling surface, C, and 5 in. with the interior point, I.

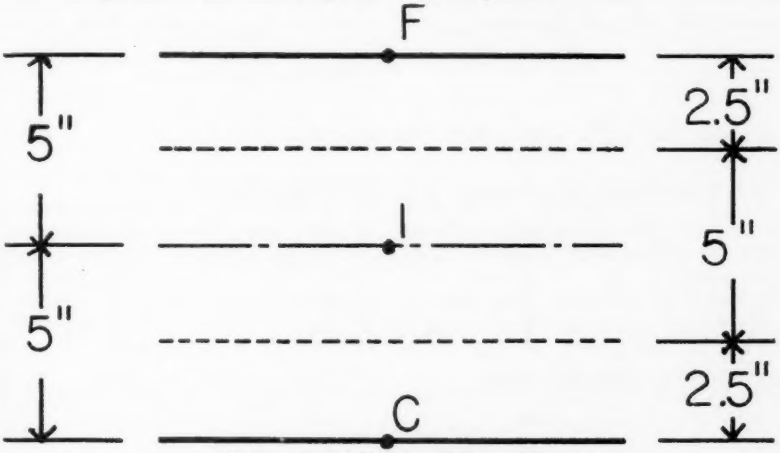

Figure 3. Subdivision of floor slab.

Then from Equation 2:

$$K_{FI} = K_{CI} = \frac{4.9 \times 1}{5} = 0.98 \text{ Btu/hr °F} \quad \text{.....(16)}$$

From Equation 11:

$$C_I = \frac{5}{12} \times 105 \times 0.18 = 7.88 \text{ Btu/°F} \quad \text{.....(17)}$$

From Equation 15:

$$\Delta\tau \leqq \frac{7.88}{.98 + .98} = 4.02 \text{ hr} \quad \text{.....(18)}$$

Later it will be seen that 1 hour will be a suitable value for $\Delta\tau$. Anticipating this result, from Equation 14 we have:

$$t_I' = .124\, t_F + .124\, t_C + .752\, t_I \quad \text{.....(19)}$$

We defer the application of this equation until we have obtained the corresponding forms for the other regions.

Now we turn to the lighting load, which was taken as 3.4 watts per ft². For the type of fixture in use, experiment had shown that 20 per cent of this went to the ceiling by radiation, 47.1 per cent to the floor by radiation, and 32.9 per cent to the room air. For our system of 1 ft², this gives:

To ceiling 2.32 Btu/hr
To floor 5.46 Btu/hr
To air 3.82 Btu/hr

Now this radiation from a high-temperature source is not going to be appreciably affected by the temperature of the receiver. Therefore it can be treated as a constant Q_E term, and for 1 ft²:

$$Q_{EC} = 2.32 \text{ Btu/hr} \quad \ldots\ldots (20)$$
$$Q_{EF} = 5.46 \text{ Btu/hr} \quad \ldots\ldots (21)$$

The floor and ceiling are each going to be warmer than the air. The free-convection coefficients are calculated to be 0.38 Btu/hr ft² °F between ceiling and air and 0.96 Btu/hr ft² °F between floor and air. Then for 1 ft², by Equation 4, using subscript A for the air:

$$K_{AC} = 0.38 \text{ Btu/hr °F} \quad \ldots\ldots (22)$$
$$K_{AF} = 0.96 \text{ Btu/hr °F} \quad \ldots\ldots (23)$$

The floor and ceiling interchange heat from surface to surface by radiation. By a calculation in the form of Equation 6, it was found that:

$$K_{FC} = K_{CF} = 1.00 \text{ Btu/hr °F} \quad \ldots\ldots (24)$$

The heat capacities are:

$$C_C = C_F = \frac{2.5}{12} \times 105 \times 0.18 = 3.94 \text{ Btu/°F} \quad \ldots\ldots (25)$$

For the ceiling we can now write, in the form of Equation 13:

$$t_C' = \frac{0.38\Delta\tau}{3.94} t_A + \frac{1.00\Delta\tau}{3.94} t_F + \frac{0.98\Delta\tau}{3.94} t_I + \left[1 - \frac{2.36\Delta\tau}{3.94}\right] t_C + \frac{2.32\Delta\tau}{3.94} \quad \ldots\ldots (26)$$

and for the convergence criterion:

$$\Delta\tau \leqq \frac{3.94}{2.36} = 1.67 \text{ hr} \quad \ldots\ldots (27)$$

On writing similar equations for t_F', we find:

$$\Delta\tau \leqq \frac{3.94}{2.94} = 1.34 \text{ hr} \quad \ldots\ldots (28)$$

It is seen that $\Delta\tau = 1$ hour will satisfy both Equation 27 and 28, as well as Equation 18, and it is convenient to have the calculation run in even hours. Then choosing this value we get:

$$t_C' = .097\, t_A + .254\, t_F + .248\, t_I + .401\, t_C + 0.59 \quad \ldots\ldots (29)$$
$$t_F' = .244\, t_A + .254\, t_C + .248\, t_I + .254\, t_F + 1.39 \quad \ldots\ldots (30)$$

However, we have not yet written a heat balance for the room air. This is going to depend not only on the phenomena in the room, but also on the rate and state of the supply of air. Suppose we assume a design room air temperature of 75° F and a supply temperature of 65° F. Then, on the usual assumption, the air would have to remove the 11.60 Btu/hr from the lights with a 10° temperature rise, and the rate would have to be:

$$\frac{11.60\ \text{Btu/hr}}{10\ ^\circ\text{F} \times 0.24\ \text{Btu/lb}\ ^\circ\text{F}} = 4.84\ \text{lb/hr} \quad \ldots\ldots (31)$$

Let us suppose that this rate is kept constant and the supply air temperature is controlled as necessary.

If air is supplied to our system at temperature t_S and removed at temperature t_A, then there is effectively a supply of heat to the region:

$$Q_{SA} = wc(t_S - t_A) \quad \ldots\ldots (32)$$

where:

w = rate of flow, lb/hr
c = specific heat, Btu/lb °F

Note here that $t_S - t_A$ is not a temperature *difference* but a temperature *change* of the air as it passes through the system. (This will be discussed more thoroughly in the next paper of the series.) For our system, w = 4.84 lb/hr and c = 0.24 Btu/lb °F, so that:

$$Q_{SA} = 1.16(t_S - t_A) \quad \ldots\ldots (33)$$

Then the total heat flow to the room air is:

$$Q_A = 1.16\ (t_S - t_A) + 0.38\ (t_C - t_A) + 0.96\ (t_F - t_A) + 3.82\ \text{Btu/hr} \quad \ldots\ldots (34)$$

Now if we were to follow the same scheme as with the other regions of the system, we would equate this to the rate of heat storage in the air. But the heat capacity of the air is very small; for example, with 10 ft ceiling C_A would be $10 \times 0.075 \times 0.24 = 0.18$ Btu/°F, compared with $C_F = 3.94$ Btu/°F. This reflects a fact of common experience, that the temperature of the room *air* will adjust itself very quickly to a change in the imposed conditions. Compared with the $\Delta\tau = 1$ hour which is satisfactory for the other regions, we will not make any serious error if we assume that the adjustment is instantaneous. Mathematically, this means that we write:

$$Q_A = O \quad \ldots\ldots (35)$$

and from this and Equation 34 we get:

$$t_A = .384\ t_F + .152\ t_C + .464\ t_S + 1.53 \quad \ldots\ldots (36)$$

Note that in this equation there is no primed symbol. The room air temperature is always to be calculated from the present temperatures of the other regions, not from the past temperatures.

With Equations 19, 29, 30 and 36 we are prepared to solve a problem proposed by Leopold which he designated as Problem A. He assumed that the entire system was initially at the design temperature, 75° F. At time zero the lights are turned on and the cooling system is started. What happens if we continually supply air at the design rate and at the design supply temperature of 65° F? (It is recognized that this is not the normal method of operation; that will be discussed later.)

As a first step in the solution we substitute the fixed value, $t_s = 65°$ F, in Equation 36 and obtain:

$$t_A = .384\, t_F + .152\, t_C + 31.7 \quad \ldots\ldots (37)$$

With the initial values, $t_F = t_C = 75.0$ °F, this gives:

$$t_A = 28.4 + 11.4 + 31.7 = 71.9\ ^{\circ}F \quad \ldots\ldots (38)$$

Literally, this says that *at* time zero, (actually, very soon after time zero) the room air temperature becomes 71.9° F.

Next, Equations 19, 29 and 30 are used to find t_I, t_C and t_F at the end of the chosen time interval, 1 hour. Then these values are used in Equation 37 to find the air temperature at that time. This series of calculations is repeated for as many intervals as necessary.

The manual solution of this type of problem can be greatly facilitated by the use of an operation guide and a tabular computing form. These are shown in Table I.

The first part of the table indexes the coefficients and the constants needed. Each column represents one of the equations. Each row, except the last, represents the factors by which a given temperature is to be multiplied. The G row represents the constant additive terms. For convenience, G_A will here include the term due to the constant value of t_S, as shown in Equation 37.

The second part of the table gives the numerical values derived from the data of the problem. In practice, only this part is needed, and the first part of the table can be omitted when the meaning of it has been learned.

The third part of the table shows the calculations for the first two hours. Note again that t_A is calculated from present temperatures.

The load on the cooling system can be derived from the fact that, at time zero for example, the room air would have to be cooled only from 71.9° to 65.0°, or 6.9°, instead of the design value of 10.0°. The load is then only 69 percent of the design value, even though the room air temperature is below the design point.

It was noted that the system would not ordinarily be operated with a constant supply temperature. More commonly, a thermostat would control the supply air in such a way as to maintain a constant room air temperature. Leopold called this Problem B. The same equations can be used to investigate what would happen under this condition.

The first step is to solve Equations 34 and 35 for the supply air temperature, giving:

$$t_S = 2.16\, t_A - .827\, t_F - .328\, t_C - 3.29 \quad \ldots\ldots (39)$$

The assumed constant value of t_A, 75° F, can be written in this equation, giving:

$$t_S = 158.7 - .827\, t_F - .328\, t_C \quad \ldots\ldots (40)$$

The constant value of t_A can also be combined with the G terms in the other equations. The resulting operation guide, comparable with the second part of Table 1, is shown in Table II. The first set of computations is also shown.

TABLE I

Solution of Leopold's Problem A.

Part one

	I	F	C	A
I	F_{II}	F_{IF}	F_{IC}	
F	F_{FI}	F_{FF}	F_{FC}	F_{FA}
C	F_{CI}	F_{CF}	F_{CC}	F_{CA}
A		F_{AF}	F_{AC}	
G		G_F	G_C	G_A

Part two

I	.752	.248	.248	
F	.124	.254	.254	.384
C	.124	.254	.401	.152
A		.244	.097	
G		1.4	0.6	31.7

Part three

$\tau/\Delta\tau$				28.8
				11.4
				31.7
0	75.0	75.0	75.0	71.9
	56.4	18.6	18.6	
	9.3	19.0	19.0	29.0
	9.3	19.0	30.1	11.4
		17.5	7.0	
		1.4	0.6	31.7
1	75.0	75.5	75.3	72.1
	56.4	18.6	18.6	
	9.4	19.2	19.2	
	9.3	19.1	30.2	
		17.6	7.0	
		1.4	0.6	
2	75.1	75.9	75.6	

TABLE II

	I	F	C	S
I	.752	.248	.248	
F	.124	.254	.254	-.827
C	.124	.254	.401	-.328
G		19.7	7.9	158.7
$\tau/\Delta\tau$				-62.0 -24.6 158.7
O	75.0	75.0	75.0	72.1
	56.4 9.3 9.3	18.6 19.0 19.0 19.7	18.6 19.0 30.1 7.9	 -63.0 -24.8 158.7
1	75.0	76.3	75.6	70.9

In this case, note that at time zero the room air has to be cooled only from 75.0° to 72.1°, or 29 percent of design load. At the end of the first hour the load is 41 per cent of design. If the calculation is continued for 8 hours it will be found that fractional load still becomes only 64 percent.

These results agree quite well with the solutions obtained by the hydraulic analog as shown in the reference paper. Better agreement can be had by a different choice of rate and state of the supply air, but the 10° design rise is used here because this makes it easy to visualize the fractional load on the cooling equipment.

With the "tools" at hand, namely, the set of working equations, we are prepared to study the response of our system to a wide variety of imposed conditions.

TOOL CHESTS AND MOTHBALLS

LAURIE R. WALLACE

THE AUTHOR

Early training consisted of seven years in the design section of Morse Dry Dock and Repair Co., Brooklyn, N. Y., special courses in Naval Architecture and Marine Engineering at Pratt Institute, Brooklyn, N. Y., about 16 years in Building Construction. From early 1937 to date, Civil Service with the Navy, seven years of which was in the Design Section Engineering at the Brooklyn Naval shipyard and since February, 1953, to date, in the office of the Assistant Industrial Manager, U.S.N., 6 N.D., and Design Senior Civilian in the Office of the Supervisor of Shipbuilding & Naval Inspector of Ordnance, Jacksonville, Florida. He is a member of the Florida Engineering Society, the Propeller Club, Port of Jacksonville, and an Associate Member of the U. S. Naval Institute. His home is in Jacksonville, Florida. Presently, Supervising Contract Specialist, Assistant Industrial Manager.

Much has been said and written about our gigantic "Fleet in Being," referring of course to the Reserve Fleet in "mothballs." Strictly speaking, these vessels are preserved and dehumidified and in most cases annually, or every five years or so are hauled out for inspection, painting or otherwise brought into a nearer state of readiness in case of reactivation. This is as it should be, and for the infinitesimal cost compared to replacing these vessels new if we did not have them, it is rightly considered one of our most economical investments in the total National Defense Program.

However, this article was not written to extol the praises of the Reserve Fleet, of which there should be more, but to call attention to that phase of shipbuilding, re-activation, repair and conversion of all types of vessels if we needed them in a hurry, which could happen. That is, our reserve shipyards and their present state of readiness.

From 1946 to 1949 the writer had the most interesting work of allocating every reserve vessel in the District to this or that shipyard for reactivation back into operating service in a given time. This was done by loading up the then existing shipyards in operating status and some that had ceased operation but at that time were still available for quick reactivation. So many vessels of certain sizes and types were to be sent to each yard on a time schedule so that the Chief of Naval Operations could depend upon building up the necessary task force, convoy escorts, patrols, minesweepers, minelayers and all the other District Crafts as required

without entirely disrupting the domestic economy of private vessel repairs.

In addition to the reactivation of the Reserve Fleet, a new construction program was estimated for a possible future "M" day. The writer also helped to assay and estimate the allocations of new construction in the District based upon the accomplishments and facilities of the then existing shipyards whose World War II record had been not only good, but extremely outstanding.

Due to changing times and conditions, such as the Korean incident and the present tense Far Eastern situation it is best to give no details or true locations in what follows. Anyway, I returned to my office's Facility Division after several years in the Design Section. The changes in the intervening years during my absence were not startling, amazing or even unusual, but changes there were.

One most noticeable item is the amount of time given to the disposal of machinery, equipment, wooden buildings and other shipyard details that at one time were so very necessary to our enormous and vital shipyard construction program of World War II. This has been brought about by obsolence and deterioration, which in the case of temporary wooden buildings, also constitute a fire hazard. However, during the past five years there has also been a tendency to dispose of some equipment on the basis that it was "surplus to our needs." I would question this on the basis of past experience. It was needed in the past, it was not obsolete, neither was it wornout scrap. It may be needed again so why sell it as used equipment for a fraction of its acquisition cost. This acquisition cost was in one-hundred cent dollars. Replacement today will cost about three times as much. In an emergency it would not only cost much more but the Navy might have to wait 90 to 180 days to get it.

The U. S. Navy was not responsible for the wholesale selling out of the Nation's shipyards that had built the gigantic merchant fleet, but before the sellout was complete the Navy had the foresight to acquire a majority of the best of these yards. In some instances it was found upon the first inventory that a lot of the best equipment had been sold to the highest bidder at the low ebb of a declining market for such material at that time. After the war was over, we had a very large surplus of ships of all types, so there was very little new ship construction ordered by commercial interests. This made it so difficult to sell ship construction machinery and tools that the majority of this material sold for a song. You guess who sang the song.

Now, when the future outlook has some dark clouds on the horizon it is time to re-evaluate the existing reserve facilities with a view to estimating what each plant will need to accomplish its expected task "if" we should suddenly be called upon to reactivate them.

One does not expect to find up to half or more of a ship's machinery and equipment stripped out before it is deactivated and mothballed into a reserve fleet for future use, but some of our reserve shipyards may be that way or nearly so. The first thoughts or glances at this situation by those who should know, would cause them to say that this estimate of the stripping of the shipyards is too high, but on second thought it might be best to look closer. So I will try to make this clear in a practical way by assuming that an emergency dispatch No. 1 is received to immediately activate any one of several reserve shipyards.

To bring about this situation it will

first be necessary to also assume that the shipyard we have picked at random is best suited for the construction of a certain class or type of vessel and that the Naval Officer who has cognizance of this shipyard has a coded dispatch informing him how many vessels of a certain type are required and when. Also assume that a letter of intent has been received and that a group of key management and technical personnal have been gathered together for awakening this sleeping giant. The first conference would no doubt be with some local bankers to handle the pool funds, then the City officials and then the Union leaders, if any. While this is all going on the technical personnel have received the contract plans and specifications of the craft to be built, this will tell them how big, how much, and how long the job is, what materials and labor will be needed and last but not least, what they have to do the job with. In other words, what kind of a shipyard have they got to build these vessels in? Of course, while all this preliminary work is progressing there will be several large office type file cabinets getting filled with copies and answers to correspondence covering every phase of shipbuilding, from allocations and priorities to launching ceremonies, not to mention re-training or first-training hundreds of male and female shipworkers to staff the yard and trying to hire good experienced operators away from other yards that will be trying to expand for the same emergency.

Anyway, to get back to the shipyard which has been idle, say since the end of World War II, the newly organized technical staff gives it the old familiar "once over" then the fun begins. They all shout "Where's the welding machines? Where's the adding machines? Where's the hand tools? Where's the spare parts? Where's this, where's that, etc.

By lunch time they will calm down and someone will suggest looking at the inventory and the records of the machinery and equipment that is supposed to be in this mythical shipyard. This is where they get another jolt. The Plant Account cards are all there, or a new and different edition of the original cards have taken their place, but in lots of cases many of these cards will bear a notation in symbols that indicate the item or some items have been sold, transferred or loaned to some other Government agency. These sales, transfers or loans have taken place over a period of several years, so after a stack of correspondence and several month's time some of the missing items will return, but not all in good condition for immediate use. Then it is going to be necessary to order new items and hope you can get the essential machines, parts and equipment to accomplish the mission.

There are certain elements of shipyard furnishings, such as drafting tables, cafeteria equipment and office machinery that can be replaced on fairly short notice from domestic sources, or other Government agencies, but when it comes to spare parts for some of the large production machines or a whole host of necessary small machines, cranes and special tools that may, in the intervening years, have become obsolete, we have a horse of quite a different color. The spare parts have been sold or scrapped, no new ones are available, even the manufacturers of some of the items may be out of business. So the only way to keep the old reliable machines or equipment running is to make new parts, or scrap the whole machines for new modern counterparts. This is not only expensive but the time delay can be disastrous.

One of the most essential elements of any shipyard, or any war production

factory for that matter, is the large quantity of hand tools such as riveting hammers, acetylene torches, wrenches, drills, screwdrivers, jacks, clamps, welder's helmets, rod holders, machinists tools, reamers, stillsons, crescents and a whole host of other small tools that are not personal to the type of mechanic hired in a big hurry to build ships for an emergency. These must be available for use and issued on tool checks. Where are they? Most of the hand tools that furnished the new war-built shipyards of World War II are scattered to the four winds because somebody decided that as the acquisition cost for each tool was less than $100.00 or some such figure, they were expendible, so if there were any left over after the war they should be sold as the property of the civilian management. This was the big mistake, because even though the management replaced lost and damaged tools out of his profits or operating cost, they (the tools) still belonged to the Navy. This was a replacement of Government property. Regardless of the small cost for individual items the total cost to the Government in some cases ran over $600,000.00. This figure included steel scaffolding, air hose, gas hose, water hose and many other necessary items that should still be on hand and available for use in our mothballed shipyards. The old saw about locking the stable door after the horse is gone applies here. We have a lot of locked stable doors but a lot of the horses have gone including the saddles, bridles and water buckets too.

It may be true that none of our reserve shipyards are as badly off as pictured above, but if we keep disposing of the essential parts and tools in one yard because we have a possible surplus in another yard, or warehouse we may end up with too many empty stables.

That is the picture of what is now and might be worse in the near future if we do not do something about it. As it is wrong to knock anything unless one has a solution to improve it, a recommendation for improvement is now in order.

As first things should come first, the basic concept is, "Do we want to keep the Reserve Shipyards for possible future use?" If the answer is "Yes" then we have a starting point in the true preservation of them. So, to start, one cannot preserve a wooden building for any reasonable cost over a ten or twenty year period unless it is moved inside a museum built of masonry. One must remember that most of our wooden shipyard buildings were built in a big hurry out of green lumber by, in some cases, green carpenters. Several of the buildings are now falling apart and have reached the point of costing more for repairs than they cost to build as well as being a fire hazard from now on. So, the only solution here is to slowly but surely replace the wooden buildings with masonry, concrete block, brick, stone or monolithic construction best suited and least expensive to the location and a new roof guaranteed for twenty years against the elements including fire and hurricanes. There are a lot of other elements of maintenance, such as new cross ties under the railroads and road repairs that are a waste of time and money to rebuild prior to reactivation, but the buildings, cranes, shipways, firemains, security fences and last but not least the essential machines, furnaces, plate rolls and all of the small tools that take long replacement time must be on hand and stored within the permanent buildings.

It is costing a sum in the neighborhood of $40,000.00 a year to maintain the twenty-four hour security watch in the average Reserve Shipyard, so why spend this money in addition to more than double the $40,000.00 per

year for nailing up loose boards, fixing leaky roofs and painting large areas of many wooden buildings that in the next twenty years will have cost millions to maintain and then be worth nothing, whereas, if these buildings are replaced with masonry construction they will be good for the next fifty to one hundred years. Also, they will better preserve their valuable contents. The main point here is to avoid destroying a dilapidated wooden building unless there is enough money appropriated to replace it at the time of demolition with a permanent structure. It is true that in many of the Reserve Shipyards there are some good steel and masonry structures that will last, with a minimum of maintenance, well over the next 40 years. This fact only goes to prove that the wooden buildings that were built in a hurry at a time of high priority of steel and masonry construction should now be replaced with permanent structures. Then we will have something worth the guard's time to watch. If this replacement program was accomplished in the near future, the dry storage space made available would help pay the cost of the buildings by eliminating the costly lease and rental space now being used for the storage of the many items of Government-owned defense material that would be taken out immediately if an emergency which was considered big enough to even think about reactivating the shipyard should arise. Such items as vehicles, weight handling equipment, small boats, aeroplane engines and marine engines, Government-owned, and assigned to various shipyards which are sometimes stored out in the weather for periods of over a year. These are the items that would be kept in much better condition if placed under cover and under guard in a reserve shipyard. There is more economy in using Government warehouses for Government property of such a nature than leasing costly private property notwithstanding any arguments to the contrary.

The above is put forward for the good it may do and as a guide to those whose mission it is to guard our reserves, be they ships or the plants to build or maintain them in.

THE TRANSPORT HELICOPTER

ACKNOWLEDGEMENT

This article was delivered as a lecture to the Institution of Mechanical Engineers in London on April 29, 1955. The lecturer was Dr. Igor I. Sikorsky, Engineering Manager, Sikorsky Aircraft Division, United Aircraft Corporation, Hartford, Connecticut. It was published in the May, 1955, issue of *The Chartered Mechanical Engineer*.

The transport helicopter is not merely another type of aircraft or even another vehicle of transportation. It seems to be more than that because, in several important respects, it may be considered as being the most universal vehicle ever created and used by man. This conclusion may be confirmed by the following comparison with other means of travel.

As a rule, every ground vehicle, from the pack animal to the railroad and automobile, is in need of a trail or road from the point of departure to the point of arrival. This is also true with respect to ships which require a waterway sufficiently deep and free of ice along the entire route to be followed. Indeed, the airplane is free to fly anywhere, but its departure and arrival necessitate the availability of a hard-surfaced airport with a long runway, or a deck of an airplane carrier.

In contrast with this, the helicopter requires neither a prepared space for departure and arrival, nor a road to follow. It is free from both. It approaches closer than any other vehicle to the fulfilment of the ancient dreams of mankind which were woven around a flying horse, the magic carpet, and the like.

The universality of the helicopter is not limited to the above factors. There are two more. Practically every vehicle used by man is limited with respect to the load it carries, not only as regards weight but also with respect to the size or bulk of the object to be transported. Such is the case with the railroad, truck or airplane. Indirectly, this is equally true with respect to the steamship because, as a rule, any object or cargo must be delivered to and from the ship. Such limitation does not exist where the helicopter is concerned. Here only the weight limitation must be observed but not the length or bulk of the objects to be carried. This feature is of tremendous importance and has already been extensively applied by military as well as by commercial operators of helicopters.

The third unique feature of the helicopter is its ability to pick up and deliver its own cargo without outside assistance. The loading and unloading of a train, truck, or airplane, as a rule, require personnel and equipment available for the work. The helicopter,

on the other hand, can pick up virtually any of its cargo and deliver it exactly at the destination point. It can, if necessary, complete both the pick-up and the delivery without alighting. This faculty, combined with the previous ones, expands the sphere of usefulness of the helicopter beyond anything which we can visualize at present. Indeed, it will really become valuable when aircraft of considerable lifting capacity become available which can definitely be expected in the very near future.

HISTORY

The idea of the helicopter is very old and probably antedates those of the airplane or even the balloon. Over four hundred years ago Leonardo da Vinci made sketches of a man-carrying helicopter.

In France, around 1784, Launoy and Bienvenue made a flying model of a helicopter. In England, around the middle of the nineteenth century, the famous student of flying, Sir George Cayley (1773-1857) produced a project and made a model of a power-driven man-carrying helicopter.

During the latter half of the nineteenth century several other projects were made and interesting flying models demonstrated. In 1907 Louis Breguet was apparently the first man to take off in a helicopter. In 1909 I began work in aviation by designing a helicopter with a motor of 25 h.p. This motor, the best available at that time, proved inadequate. Between the 1914-18 and 1939-45 wars, the autogyro was created by Juan de la Cierva in Spain and several helicopters were produced in different countries, with gradually increasing degrees of success until, around 1937, Dr. Heinrich Focke produced what was probably the first practical helicopter. It was capable of rising to an altitude of several thousand feet, flying from town to town, making autorotative landings, and demonstrating full control in flight.

In 1939 in Stratford, Connectiuct, the American VS-300 made its first flights. This was the world's first successful single-main-rotor helicopter and led, in 1943, to the R4 which, at Bridgeport, Connecticut, became history's first production helicopter.

During the 1939-45 war these helicopters were used for the first time in actual operation for liaison and rescue missions. Later, several commercial airlines inaugurated services with somewhat larger helicopters of similar general design.

It may be considered that the helicopter reached its maturity during the Korean conflict. Korea has been rightfully called 'the proving ground of the helicopter.' Helicopters moved in with the first United Nations' troops in June 1950. They delivered replacements, food, medical supplies and ammunition to the battle lines and laid communication wires. It is recorded that Army engineers flew a bridge into position one piece at a time so that troops could move up into new territory. On another occasion S-55s flew 34,000 lb. of supplies to infantrymen who were temporarily isolated. Thus, in the short period of a few weeks, what had been military theory, in so far as helicopter operations were concerned, became military fact.

As time progressed, the helicopter rapidly demonstrated its outstanding value in rendering the greatest possible variety of useful services to the Armed Forces. It became the chief means of travel for battle commanders

and enabled them to visit, inspect and supervise even the front-line positions to an extent never before possible. Carrying of men and materials assumed substantial proportions. For instance, a marine helicopter transport squadron of the First Marine Aircraft Wing in Korea, in 558 hours of flight time, carried almost 1,700,000 lb. of cargo. This undertaking, was a five-day effort to keep two regiments of Marines completely supplied by helicopter.

Perhaps the proudest record is written in the roster of men who are living because the helicopter was on hand to save their lives or to deliver them to first-aid stations for medical treatment. The records of a single service, Air Rescue, have the names of 9,500 men who owe their lives to the helicopter. To this number must be added the rescues accomplished by the Navy, the Army and Marine Corps. Conservative reports have set the total number of helicopter evacuees at nearly 20,000. Of this number about 1,500 men were rescued from behind enemy lines which achievement earned for the helicopter the truly honorable nickname of 'Guardian Angel.'

Again, when the cease-fire negotiations were started and 5,000 Indian troops were assigned to the neutral zone, it was the helicopter that transported them so that they would not have to march over forbidden territory. Korea asked the question and the helicopter answered efficiently.

PRESENT STATUS

The present status of the art may be illustrated by the following brief record of facts and figures.

The official world record for speed is 156.005 m.p.h. reached by pilot Warrant Officer Billy Wester in August of 1954. The official world's helicopter altitude record of 24,500 feet was established at Bridgeport on 17 October, 1954, by this same pilot. Both these records were achieved by the American S-59 Army helicopter powered by a 400 h.p. Artouste Turbomeca turbine.

The longest helicopter non-stop flight, 1,234 miles, was completed by test pilot Elton J. Smith piloting a 47-D1 Bell helicopter, powered by a 200 h.p. Franklin engine, which flew from Ft. Worth, Texas, to Niagara Falls, New York, on September 17, 1952.

The heaviest useful load carried was well in excess of 10,000 lb. lifted in the course of a routine engineering test by the American S-56 Marine assault helicopter powered by two Pratt and Whitney R-2800 engines. This flight, with chief pilot, D. Viner, at the controls, took place in January 1955.

One of the most significant long-distance flights was the crossing of the Atlantic by two helicopters of the Air Rescue Service in the summer of 1952. The helicopters used were two S-55s powered by Pratt and Whitney Wasp 600 h.p. engines. Helicopter 'Hop-along' was piloted by Captain Vincent H. McGovern and Captain Harry C. Jeffers, while 'Whirl-o-way' was piloted by 1st Lt. Harold W. Moore and Captain George O. Hambrick. This flight was conducted under frequently adverse weather conditions, and demonstrated the ability of the helicopter to be ferried to virtually any point on the globe provided refueling arrangements would be available at intervals of, say, 1,000 miles or so. This is important, not as a forerunner of transoceanic flights by helicopter, but as a demonstration showing that whenever helicopters would be needed for regular or for emergency services in any part of the world, they could be ferried

under their own power. This is particularly important for the much larger helicopters which are definitely coming for both the military as well as commercial services.

The foregoing figures may serve as an illustration of the present status of the art.

Equally indicative and important will be the following brief review covering some of the recent helicopter activities, both in emergencies as well as in regular service.

RECENT ACTIVITIES

Los Angeles Airways. Los Angeles Airways (L.A.A.) is at present operating seven Sikorsky helicopters, three S-51s and four S-55s. Total time accumulated on L.A.A.'s seven aircraft up to January 1955, was 28,925.50 hours. Total poundage of mail carried to that date was 40,000,000 lb. with air express and cargo totalling 800,000 lb. It is interesting to note that the first three S-51 helicopters operated by L.A.A. have accumulated, to date, 8,522, 7,960, and 5,906 flying hours, respectively.

In 1954, 12,378 trips were flown (post office, passenger, and express) which averages 1,032 trips per month.

The Los Angeles helicopter operation is the world's first full-scale scheduled helicopter mail service. Numerous other firsts are credited to L.A.A., a few of which are:

(1) to design and contract for complete roof-top passenger facilities;

(2) to develop and operate a complete system of heliports independent of public utilities such as lighting or other navigation aids;

(3) to initiate and develop the concept of municipally-furnished heliports on a nominal cost basis, system-wide.

New York Airways. Five S-55 helicopters are now being operated by New York Airways (N.Y.A.) which have reached a combined total flight time of 14,160 hours as of February 1955. It should be noted that two of these aircraft have passed the 3,000-hour mark, the first S-55s to attain this time.

N.Y.A. operates a mail and freight service as far north as Bridgeport, Connecticut, and south to Trenton, New Jersey. Passenger service is provided to Stamford, Connecticut; White Plains, New York; Trenton, New Jersey and New Brunswick, New Jersey, as well as the inter-field connexions between Idlewild, LaGuardia and Newark Airports.

The total number of passengers carried up to February 1955 was 10,068; mail 6,074,283 lb. and freight 487,684 lb. Since the inception of this phase in November 1954, through February 1955, 159,322 lb. of cargo have been carried by air express.

Sabena Belgian Airlines, Belgium. Sabena Belgian Airlines started its scheduled air mail routes 1 August, 1953, and its scheduled passenger routes on 1 September, 1953. Sabena is now operating four Sikorsky helicopters, the utilization of each aircraft being five hours per day in winter and seven hours per day in summer. The yearly unit utilization is figured at 1,750 hours. Total time accumulated up to February 1955 is placed at approximately 8,800 hours.

The first demonstration flight from Brussels to Paris was made 20 December, 1953, in one hour fifty minutes

with the landing being made at Esplanade des Invalides. The flight could have been made in one hour thirty-five minutes but the helicopter landed in a field outside Paris and waited fifteen minutes so that it would arrive on schedule.

Sabena's pioneering flight from Brussels to London was made on 7 July, 1954, in two hours forty-seven minutes. This time could have been shorter also, but the helicopter followed the original Bleriot route across the Channel.

Both figures are substantially better than could be achieved by any other means of travel from the heart of one of the above cities into the heart of another. Furthermore, at the present time there are under construction, or even undergoing tests, new types of helicopter which would be capable of covering the above distances in approximately 70 per cent of the time mentioned above or even less. It is unnecessary to stress that, in the very near future, such aircraft would represent excellent and most important means of travel over such distances.

Several other lines have already purchased helicopters, and have started operations.

Extremely promising and indicative also are the achievements of several non-scheduled operators who have used helicopters for special projects. Very interesting results have been achieved by Okanagan Airways, Ltd., which has operated helicopters for a variety of special missions, including prospecting and assisting in the installation of high-tension electric lines over inaccessible high mountains in British Columbia. In the course of this operation thousands of men and hundreds of tons of supplies were transported and a most interesting and new field of usefulness for the helicopter was established and demonstrated. Some of the cargoes carried included materials for the erection of a village of 21 houses to house the personnel working on the project.

Very interesting also was the successful operation in Northern Labrador where helicopters were used for prospecting and carrying personnel, all necessary equipment, food, fuel, instruments and machinery for drilling, etc. A group of prospectors was able to do a job more completely and within a fraction of the time that would have been required if they had traveled by any other means.

Another interesting example is the excellent work performed by the helicopters in the Belgian Congo. Certain districts there were so badly infested with malaria and other diseases as to result in a considerable loss of lives among the natives. This condition also precluded the possibility of utilizing otherwise valuable territories by the white man.

In several such cases, the use of the helicopter permitted control of this disease to such an extent that the mortality rate was reduced to a figure of less than 1 per cent of what it had been. This factor earned for the helicopter gratitude and popularity among the local population and opened vast new territories for use.

Perhaps most encouraging is the fact that in peacetime emergencies, helicopters have proved just as valuable and important as they did in war. During the recent floods in the Netherlands, several hundred lives were saved by the use of helicopters. Numerous others were saved under various emergencies in Alaska, in Newfoundland, as well as in many parts of the United States and other countries. Thus, apart from the countless number of rescues effected by helicopters during the Korean conflict, hundreds of men owe their lives to the use of the

helicopter during peacetime emergencies.

In a number of cases, military helicopters have been called upon for various services. As an example we may mention some of the activities of the 328th Transportation Helicopter Company in Germany. The missions of this company have been numerous, some of these involving flood rescue and evacuation, air supply of troops, air movement of artillery, ammunition and equipment supply, etc. One operation included the hauling of equipment to inaccessible mountain areas in Norway where micro-wave stations were being built. One of the pieces, a generator and its base plate, was delivered to the site by an S-55 in approximately eighteen minutes. Later, it was learned that when the helicopters had already left Norway and one of these generators had to be replaced, it required five men and three horses and took ten days to haul the replacement generator to the site.

During this mission, 431,885 lb. of equipment were carried in twenty-four working days by two aircraft. The total time flown, including that required to get the ships to Norway and back was 195 hr. 15 min. combined.

In July 1954, ten S-55 models were used in the stricken flood areas of Austria and Bavaria. During this time, 73 rescue, 42 supply, and 4 reconnaissance missions were flown. Total flying time for July was 697 hours. Total time flown by the twenty-one S-55 aircraft assigned to the 328th Transportation Company up to December 1954, was 4,211 hours.

Among the multitude of successful missions of various natures accomplished by the helicopter, the most impressive are still those connected with rescue operations, and the obviously deep and sincere gratitude which this modest aircraft earned from persons who benefited from its help. In appreciation of the assistance rendered during the big flood in Holland, the Queen of The Netherlands invited all the pilots of the helicopters to be her guests at the Palace. In commemoration of the outstanding life-saving achievement of the helicopters after the 1955 cyclone in Haiti, that Republic issued a series of stamps as a tribute to the rescue work done by the S-55 helicopters. Countless stories of similar nature could be mentioned and there is a huge file of personal letters from those who have been rescued and their relatives who are grateful for the timely help delivered from the skies by the helicopter.

This brief review of military, transport and rescue operations with helicopters, as well as the preceding historical review, obviously includes only a small number of all the names and facts that deserve to be mentioned. The facts and names were selected more or less at random in order to illustrate certain phases of this discussion.

TYPES OF HELICOPTER

The major part of this lecture, as well as references to the actual use of the helicopters, mostly describes the single-rotor aircraft. This has been done with no intent to withhold the great credit which is certainly due to a number of designers of tandem, jet-driven, and other types of helicopter, nor to deny their value. This approach has been used because the author is much more familiar with the single-rotor helicopter, which he considers to represent the most promising configuration and because most of the successful practical applications of the helicopter in war and in peace have, so

far, been achieved with single-rotor helicopters.

The use of the term 'Transport Helicopters' may call for certain explanations. For both the military and the commercial applications, it is possible to foresee, in the immediate future, the development of two distinct lines of design. The first would correspond and be similar to the airliner or transport airplane. The second would be a freight and cargo carrier, and would be a craft in its own class with virtually no parallel in any other aircraft or even in any other vehicle of travel.

Passenger Transport. The first type would need very little description because it would be essentially the further development of the modern helicopter as currently used. It means an aircraft with a body-fuselage with interior arrangements essentially similar to that used in corresponding military transports or airliners. In like manner this aircraft would carry all its useful load of passengers and luggage or cargo inside its body-fuselage as on an airplane, a truck, or a railroad car. Such aircraft would usually be equipped with familiar features of convenience and comfort of the modern airliner, such as soundproofing, comfortable and attractive interior arrangements and seating, proper heating and ventilation, etc. With respect to certain items, however, the helicopter may gradually become somewhat different from the airliner. For instance, in the helicopter it would be desirable to use larger entrance doors, or more of them, in order to expedite the loading and unloading of the aircraft in the case of short-range flights. Furthermore, it would be desirable to use larger windows because, as a rule, the view from a helicopter cabin is completely unobstructed and the helicopter generally flies at lower altitude and, in the majority of cases, offers much more interesting scenery than that which could, on the average, be viewed from the airplane. This and other similar features would gradually be developed in co-operation with the operating organizations.

Freight Type. The second and very interesting type whose appearance may confidently be expected in the near future, would be a special freight-cargo helicopter which would be specifically designed to lift any type of object or load, including large and bulky ones, and to carry them on the outside, suspended below the body of the aircraft.

In the crane helicopter it is possible to use any conventional helicopter-lifting rotors and methods of control, power plant, transmissions, etc. The main difference would be in the body, location of the pilot's cabin, landing gear, and powerful, special lifting-crane devices that would allow for picking up an object, if necessary with the helicopter hovering over the ground. The cargo helicopter may virtually have no fuselage body as we know it and may simply represent a flying frame or possibly have a needle-like fuselage of small cross-section adequate to accommodate the transmission and other accessories, and either a hoist or other arrangement that could be used to suspend and, if necessary, to lift the loads.

Study is being conducted as to the best configuration and the best location for the pilot's cabin in such aircraft. There are reasons for a novel arrangement in which the pilot's cabin would be suspended below a narrow tubular fuselage substantially behind the center of gravity of the aircraft. Indeed, such location would somewhat obstruct upward vision from the pilot's cabin. However, with the very narrow fuselage, the pilot would still have much better vision even in that direction than would the pilot of a 'Zeppelin' or 'Blimp' and yet the dirigible control

cabin has proved to be satisfactory. Vision forward would be satisfactory while vision downward would be excellent.

The main advantage of such arrangement would be that the pilot would have excellent vision of the object which he is to lift, of the whole procedure of attaching and lifting and, finally, would have excellent opportunity to direct the aircraft in a way that would permit bringing and lowering the object, not merely on the geographical location but actually and precisely where it may be needed. This would permit, for instance, carrying and lowering a transportable house directly upon its foundation, delivering high-tension towers in a vertical position and placing them accurately on their bases and, in fact, would combine the countless number of problems of transportation with the problems of actually lowering of objects or materials, erecting machinery or sections of a bridge, etc., directly where they are intended to be. An excellent beginning of such service has already been made by the Armed Services and private operators, using ordinary helicopters. Among objects carried in such manner were jeeps, pieces of artillery, long pipes, long posts, loads of lumber to construct a village of 21 houses, light airplanes, helicopter bodies, miscellaneous pieces of machinery and equipment, food, fuel and a great variety of other objects including a 300-lb. cross which was lifted and set down directly on top of a church steeple.

Such were the services rendered by the helicopter with relatively modest power and lifting capacity and with conventional arrangements which did not make it possible for the pilot to see the cargo that was picked up and lowered in place. It would consequently be difficult to overestimate the immense amount and varieties of the extremely useful services that could be rendered by a cargo aircraft with adequate lifting power and proper location of the operator's cabin. It is this type of helicopter which will promote, within the next decade or two, a whole series of new enterprises and industries that would depend on the possibility of making direct deliveries of objects which, owing to their length or bulk, could not otherwise be transported in assembled, ready-to-use form.

POSSIBLE FUTURE DEVELOPMENT

An attempt will now be made to foresee the direction of the possible future development of the helicopter.

Simple Type. First we will analyze the case of the pure helicopter. By this term is meant an aircraft in which all lift and forward components are derived exclusively from the action of one or several lifting rotors. There are reasons to maintain that the operating speed of such aircraft will never be much in excess of 200 m.p.h. Several methods are being studied for the further increase of speed of the pure helicopter. Besides a general refinement of design and increase of power available, they include special designs of blades, different types of boundary layer control and, possibly, the use of supersonic blades.

I believe that some type of boundary layer control to delay stalling would produce interesting results although the increase in speed would not be great. In regard to the second method, it would seem that considerable difficulties, apart from the low efficiency and the noise factor, may preclude the practical use of supersonic rotors.

One of the major problems involved is connected with the fact that in for-

ward flight a certain section of the blade would have to make the transition from subsonic to supersonic and back at each revolution. The adverse effect of such operation would be tremendous and alone might create insurmountable obstacles to the use of supersonic blades.

Compound Type. A speed somewhat higher than the velocity of the pure helicopter could be obtained by the use of the compound helicopter or 'gyrodyne.' By this term is meant an aircraft which, besides the lifting rotor, has small auxiliary wings and probably propellers or jets. As the aircraft accelerates, the wings will carry part of the load and, with the main rotor being unloaded, it would be possible to postpone or prevent stalling of the retreating blades and consequently exceed the speed range of the pure helicopter by perhaps 50-75 m.p.h. or even more.

As a rule, the wings and propulsive members of the compound helicopter would be, at best, useless during hovering. Consequently, with equal hovering ceiling and other conditions being identical, the compound helicopter should, as a rule, be expected to have less pay load than the pure helicopter of comparable size and power. This fact, together with its greater simplicity and smaller maintenance cost, would most probably result in the pure helicopter remaining, for an indefinitely long period of time to come, a useful and popular type of aircraft that would be extensively utilized for a great variety of short range missions. Nevertheless, for intermediate ranges, the compound helicopter, with its higher speed, may offer sufficient advantages to justify its use.

The simplest form of compound helicopter may be represented by a simple helicopter which carries some auxiliary means of propulsion, usually one or more propellers, driven from the main source of power or from auxiliary engines or turbines. By relieving the forward component from the main rotor, it would undoubtedly be possible to obtain higher speeds than would be possible with the simple helicopter.

Convertible Type. The more radical type, which would offer a considerable increase in speed, would be the so-called convertible helicopter. As the name signifies, it means an aircraft which can take-off vertically and hover as an ordinary helicopter and then become converted into an airplane and travel at a considerable speed, perhaps several hundred miles per hour. For landing, the ship could be reconverted into a helicopter and hover and land in the usual manner. Such aircraft are undoubtedly possible and a large number of different and frequently very ingenious projects have been made because, in fact, there is virtually an unlimited number of configurations and arrangements that could be proposed for such aircraft. I believe, however, that, as a general rule, such aircraft would always remain considerably more expensive and less efficient than either the pure helicopter or the pure airplane of equal lifting capacity. Therefore, I can foresee only a limited utilization of the convertible type, mainly for certain specific military uses.

Vertical Take-off Type. A very promising aircraft of similar potential performance is the so-called V.T.O., in other words, the vertical take-off airplane. I do not believe that it could even approach the hovering characteristics of a true helicopter with all the great safety and service significance of this regime. However, the V.T.O. should be capable of rising into the air vertically and landing with no run. Once in the air it would proceed as an airplane which, in fact, it never ceases to be. The military value of such aircraft may be substantial and it seems

that a good beginning has already been made in the production of such planes.

In respect to size, I believe there is no limitation in sight, and it would be possible to produce giant helicopters as soon as they would be needed. There are reasons to believe that, for both military and commercial operations, certain important missions would call for the service of giant helicopters.

CONFIGURATION

While it is possible to foresee a great variety of configurations using different numbers and arrangements of lifting rotors, and different methods of applying power, yet there are reasons to believe that a single-rotor aircraft, in other words, a helicopter in which all or most of the lift is derived from the action of one large rotor, would remain the most important type. At any rate, it appears so, judging from its performances and accomplishments to date. While different methods of transmitting and applying power may be visualized, yet for machines of up to 100 tons or so, the use of engines and a transmission carrying power to the rotor shaft, or directly to the rotor hub, seems to be the most practical. At present a metal gear transmission is used in the vast majority of practical helicopters. It is possible that hydraulic or pneumatic transmission will make their appearance in the future if substantial further progress, in respect to efficiency, could be achieved in their design. At present no transmission of this type could even approach the 96 to 97 per cent of efficiency currently reached in well-designed modern metal gear transmissions of helicopters.

Concerning maintenance, life expectancy and reliability of helicopter transmissions, they are all quite reasonable even at the present time and may well be expected, in the near future, to be in line with the characteristics of the best modern aeronautical engines or turbines. It is believed, therefore, that piston engines or turbines, combined with the metal gear transmission, would represent the power unit for the majority of helicopters for an indefinitely long period of time to come.

In certain cases, particularly for still larger machines, it may be advantageous to eliminate the transmission and apply the force directly at the tips of the blades in the form of jets. It could possibly be in the form that had been considered by some leading engineers and had been well analyzed and described in England by Mr. Fitzwilliams of Westland Aircraft, that is, mounting of the complete turbo-jet units on the tips of the lifting rotor blades.

While the construction of such aircraft would involve the serious engineering problem of producing a turbo-jet capable of withstanding considerable centrifugal and gyroscopic forces, it would also involve the problem of carrying heavy loads on the tips of the blades. In a super-giant aircraft of such nature, we may even foresee the blade supported by a landing gear of its own which may be retracted when the blade becomes airborne. Other methods may be suggested that would involve the use of supporting members that would be folded or removed when the blade becomes airborne or when the centrifugal force becomes sufficient to support the blade. In spite of the serious and novel problems which would be encountered, an aircraft of this type would certainly be possible. Such arrangement may become particularly interesting in a helicopter of a gross weight much in excess of 100 tons.

In respect to other characteristics, I

believe it may be expected that in future helicopters, particularly in the large ones, we will use heavier disk loadings and lighter power loadings. While our study and experience indicate the advantages of a single-rotor configuration for all sizes, and particularly for the giant helicopter, yet in large rotors it may be advantageous to use a greater number of blades of a moderate chord. There are reasons to believe that this would increase the smoothness and decrease the control loads of the aircraft.

It is very probable that aircraft engines will continue to be the principal power plant on helicopters, as at present. However, we may confidently expect increased use of the turbine because the helicopter will profit even more from its characteristics than would the airplane. It is probable that, for the multiple-engined turbine-driven helicopter, engines with the free turbine wheel would be preferable because, in the event of one engine becoming inoperative, it would be possible to obtain nearly the full power of the remaining turbines at a somewhat reduced number of revolutions of the rotor. For single-engined helicopters this would represent no advantage and consequently ordinary shaft turbines would seem to be just as satisfactory.

THE USE OF NUCLEAR POWER FOR HELICOPTERS

This discussion of different power units would be incomplete without reviewing briefly the possibility of using nuclear power as a source of energy for helicopters. There is no doubt that nuclear power could be used to drive the helicopter as soon as a suitable power plant became available.

Among the several arrangements that can be foreseen, one of the logical ones would seem to be as follows: We can visualize a turbine of generally conventional type in which the air, after being compressed, becomes overheated in a heat exchanger into which, in turn, heat is supplied from a nuclear reactor by circulating molten metal, or by some other means. The major problem in this case would still be to protect and insulate the occupants from the powerful radiation that would be created by the nuclear reactor. It is probable that on a sufficiently large machine, a reactor could be situated far in the very bow of a fuselage of the aircraft and be properly insulated, while the crew could be located far behind, in the rear end of the craft. This, or similar solutions, however, may involve certain difficulties: It is probable that, during operation, the entire aircraft, including transmission and rotor blades, would become powerfully radioactive and the blades, in turn, would spread radioactivity on all parts of the aircraft, consequently making the method of protecting the crew extremely difficult, if not impossible.

Another method would be to separate completely the reactor, together with turbines, into one unit that could be carried by the helicopter, suspended on a length of cable about 200 feet long or, if necessary, even more. By insulating either this unit or the crew compartment, or both, it would perhaps be possible to protect the occupants of the aircraft. However, in this case, transmission of power would present a serious problem.

A reasonable method would be to use the power of the turbine to generate compressed air which can be sent by conduit up into the aircraft where it can operate power turbines or possibly be sent directly into the blades to turn them by means of jets. This, however, would still involve the danger of the

stream of air passing the mechanisms inside the reactor and itself becoming infected with radiation which it would carry up into the aircraft. A safe way would be to generate electric current in the suspended reactor and send it up into the helicopter by means of wire. However, while some optimists believe that extremely light-weight generators and electric motors, weighing less than 1 lb. per h.p. are possible, yet any electrical equipment so far produced has been considerably heavier, and it remains a question of whether such light electric generators and motors can be produced.

The final arrangement, which, so far, appears to be the best, would be the reverse one. Let us suppose that the reactor, with all its accessories and the turbines directly geared to the rotor, are located in the cabin of the aircraft. However, no members of the crew occupy places in or even near the aircraft. They are all in a separate cabin which is normally suspended under the helicopter on a cable a couple of hundred feet long, and which, in fact, is never expected to be closer than that distance to the carrier helicopter. Controls will be transmitted from this suspended cabin into the helicopter by way of electricity or by other means which are entirely feasible. The aircraft would then be operated as follows:

At the onset, the helicopter is located on the ground 200 feet or more from the cabin. From the cabin the pilot controls the helicopter, takes it off, pilots it into vertical position above the cabin and, continuing slowly to climb, finally lifts the cabin and proceeds on his flight, with the cabin remaining suspended far below the helicopter. During landing, the procedure is reversed. The cabin is landed first and the helicopter landed next, some distance away. It is believed that, in such circumstances, shielding of the cabin could be accomplished within a reasonable expenditure of weight and the nuclear-powered helicopter would become feasible.

It is very probable that, in line with further developments of nuclear physics, other ways of using nuclear energy in helicopters would be proposed. In fact, a conventional arrangement may become possible if lighter and more efficient methods of protective insulation are developed.

The greatest obstacle, which will probably prevent the use of nuclear energy in helicopters for some time to come, is the fact that there may not be sufficient advantages in doing so. While very fast, nuclear-powered, possibly supersonic, airplanes with virtually unlimited flying range, would be tremendously valuable, yet practically all the missions of the helicopter are for short range, except in the case of ferrying of the aircraft, for which refuelling can usually be arranged without much difficulty. Consequently, it does not seem that the use of a delicate and very expensive source of power would be justified.

In the medium-size and large-size helicopters, it may be advantageous, in the future, to use a combined system of application of power. As basic power, this would consist of engines or turbines whose power is geared to the main rotor shaft or, in larger units, preferably directly to the huge rotor hub of the aircraft. A secondary power system would consist of a turbine or turbines driving compressors, sending compressed air through the blades and using jet power at the tips of the blades with or without superheating it. Although the combined system appears more complicated than, for instance, a pure power-driven or pure jet-driven system, yet it may offer sufficient advantages to be considered, particularly for large helicopters.

In the proposed arrangement it would be possible to utilize passages within blades of normal cross-section which, as a rule, are smaller than would be desirable if pure pressure-jet drive were used; yet for a partial jet drive, it would permit efficient utilization of the existing cross-section without the need of increasing the thickness of the blade beyond that indicated by aerodynamic and structural considerations. Furthermore, it would permit using the light but inefficient system for take-off, or for any time when a burst of power would be needed, while for ordinary cruising, it would be possible to operate under the more efficient engine and transmission system. Also, this would allow for having somewhat smaller torque compensating device or tail rotors than would be necessary if all power, including emergency power, were sent directly into the shaft, creating torque.

Finally, the compressed air system of this type could be utilized for anti-icing by preheating the air to an adequate temperature before it is channelled into the blade passages. Consequently, it seems that enough advantages are evident to warrant adding an auxiliary system of such nature on large helicopters.

In very huge helicopters of, say, more than 100 tons gross weight, it may be advantageous to apply all or most of the power directly at the outer ends of the blades in the form of either pressure jets, or complete turbo-jets mounted on the tips of the blades. A considerable number of other arrangements that would permit transmitting or generating the power at the tip of the blade have already been proposed because, particularly for giant helicopters, it would seem very desirable to eliminate the torque together with the great stresses in the center of the craft and the torque compensating device, by applying the entire power directly to the tips of the blades. So far, however, no arrangement of this nature has been tested that would approach the efficiency and general operating characteristics of a helicopter with a transmission and a torque-compensating control rotor. It is, therefore, not impossible that the conventional formula will survive even on giant helicopters. In certain designs of this nature it may be advantageous to use hydraulic, pneumatic, or electric transmission of power to the tail rotor. It may even be desirable in some cases to eliminate the transmission by using a separate power plant, say, two governor-controlled turbines, to generate the power for the tail rotor where it is required.

Concerning the configuration of the aircraft, I believe that the giant and super-giant helicopter of the future will still be a single-rotor aircraft obviously having a huge rotor with a large number of blades and a very heavy disk loading.

As time goes on, the helicopter will gradually assume the leading position as a guardian of life and property in emergencies of virtually any nature. It is probable that certain permanent arrangements will be made by the proper Government authorities, such as Civil Defense, Military Command, or others, which, in the event of major emergencies, would automatically place at their disposal, helicopters, with their crews, operated in the vicinity by transport companies.

These helicopters can carry provisions that would make possible the quick installation of such equipment as may be required by the immediate emergency. Such equipment may include fire fighting, medical equipment, instruments for detecting nuclear or biological poisons, etc. When much larger helicopters become available, and particularly with the advent of the freight-cargo type with a huge lifting capacity, such emergency equipment

would be in the bigger and more important class. These may include transportable field hospitals, fully equipped, in a container, similar to a modern trailer, but without its height and width limitations. They may carry other types of equipment that may be useful for fighting fires, for rendering assistance in floods, etc. In such instances the helicopter can be flown to any stricken area within an extremely short period of time. As a rule, helicopters would be the quickest, and frequently the only, means of travel that could bring help where it may be urgently needed and on return trips evacuate injured or others from a stricken area.

It is impossible at this time to foresee all that can be accomplished with the helicopter but there is no doubt that in the not-too-remote future it will become the leading agent for saving human lives and rendering urgent assistance in emergencies.

CONCLUSION

Throughout the history of mankind there are few factors, if any, that have influenced human life and the course of history to a greater extent than the development of the means of travel.

The first quarter of the current century witnessed the appearance of flying. The pioneering period of the airplane that was started by the brothers Wright was concluded by the tremendously important and significant flight of Lindbergh across the Atlantic, from New York to Paris, non-stop. The impact of aviation on the peacetime and military history of mankind from that time on hardly needs any further emphasis.

The middle of the twentieth century witnessed the arrival of two new vehicles of travel both of which are characterized by the elimination of certain speed barriers which, until recently, were considered impenetrable. On the side of high speed, we witnessed the arrival of the supersonic rocket-driven airplane. The possibility of man to fly with more than twice the velocity of sound, in other words, to move faster than the average revolver bullets and gun shells, represents one of the most spectacular achievements of human genius. There is no doubt that this aircraft is the forerunner of space craft and that within the lifetime of many of the present generation, man will be able to reach celestial space above the earth's atmosphere, and for the first time see and photograph the mother planet from interplanetary space. Whether or not landing on the moon can be attained within the current century remains to be seen but the opening of space travel undoubtedly will be achieved. The significance of this can not be overestimated and may, in due time, be regarded as one of the major events of all time.

On the side of low speed, the arrival of the helicopter made possible the complete elimination of the minimum speed required for a controlled flight of a heavier-than-air craft. This modest newcomer into the field of aviation, in no way nearly as spectacular as the previous one, nevertheless may have at least as great, if not greater, an impact on future human history. There is no doubt that the helicopter will prove a modest, faithful, and tremendously useful servant of mankind, capable of performing a countless number of services, either scheduled, non-scheduled, or emergency, all this in peacetime as well as in war.

We can confidently foresee great expansion of the industries that manufacture helicopters and the organizations that operate them. Both have

made a fine start. Considerable further expansion which will allow them to at least approach the scale of the present airplane industry and transport operation, can be expected. As time goes on, the wonderful characteristics of the helicopter, which have been mentioned here only very briefly, will undoubtedly contribute toward the promotion of a series of new enterprises and industries whose activities will depend largely on the helicopter. Indeed a bright and certainly an interesting future lies ahead for the helicopter.

INDUSTRIAL RELATIONS— AN INTERPRETATION

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THE AUTHOR

gained first hand experience in his subject as Industrial Relations Officer, Charleston Naval Shipyard. He is now the Industrial Manager Assistant, 6ND. His World War I experience included sub-chasing in a P.C., major fleet strikes aboard the *USS Missouri*, and duty as Chief Engineer of the *USS Arkansas*. Following the war he served as Chief Engineer, *USS Los Angeles*, OinC, Noise, Shock and Vibration Branch, Bureau of Ships, Ship Superintendent at Mare Island Naval Shipyard, and Asst. P&E Supt., San Francisco Naval Shipyard. He received his B.S. degree in Mechanical Engineering, University of California.

"Today a man to do his duty in the military services must study first of all humanity. What makes humans tick . . . you must know something of economics . . . of law, of engineering, and many of the sciences, but above all . . . you must try to understand people." This quotation from President Eisenhower's address to the men of the Citadel sums up the purpose of Industrial Relations. It emphasizes dramatically the need of the military or naval administrator to learn how to handle personnel, particularly in large organizations staffed by civilians. Naval officers assigned to air stations, supply depots or shipyards, employing thousands of civilians, meet a bewildering array of problems involving people. These problems cannot be handled in the same manner as those met aboard ship with military personnel. There is a solution to these problems however. In the past solutions were found by experience, or by trial and error. Today, solutions are offered by Industrial Relations.

James Forrestal once wrote, "The removal of human friction is a substantial part of administration . . ." This truism, recognized in both industry and the Navy, is interpreted and implemented in the term "Industrial Relations." Industrial Relations is an essential part of industrial management. It is a broad category embracing at once all aspects of personnel administration and management aimed at removing human frictions. This is done by recognition of legitimate human aspirations, the fair treatment of which is

essential to the operation of the U. S. Navy's great industrial organization, the base of the world's greatest fleet.

There may be some difficulty in grasping the relationship between the Chief of Naval Operations and workers in shipyards, air stations, or supply depots. But the relationship exists as surely *as* it does between the first and last links of a chain. Industrial Relations strengthens and maintains the relationship.

Perhaps the weakest segment of this chain is the lack of appreciation and understanding of the functions of Industrial Relations by the officer corps as a whole. Gradually, through courses such as those offered in Executive Management at Harvard and Pittsburgh, in Personnel Administration at Stanford, Management and Industrial Engineering at Rensselaer Polytechnic Institute and the course offered by Office of Industrial Relations Institute, Navy is spawning a growing group of naval administrators who grasp the import of Industrial Relations. This program parallels private industry efforts to train civilian executives along the same lines. The growing emphasis on personnel—call it human engineering, employee relations, or what you will—stems from a number of factors. Two factors stand out in historical importance, namely, the growth of the labor movement and the development of manpower shortages. The flux has been provided by accelerated industrial progress and growth. The result is Industrial Relations.

Navy has pioneered far ahead of other government agencies in its Industrial Relations program. Within the Navy the Bureau of Ships has achieved outstanding recognition of its accomplishments in the field. With more than 118,000 civilian employees who carry out its industrial work, the Bureau of Ships has more employees under its management control than any other organization in the world. How does it achieve its results? The purpose of this article is to interpret some of the fundamentals of Navy's program. It is also designed to point up the functions of an Industrial Relations officer, a job which is never sought, and is seldom understood.

Industrial Relations means many things to many people. To employees it may be the means by which an individual can realize his hopes and aspirations. It may make the difference between a beaten individual, a community charge, or a profitably employed citizen—an American on a payroll — an individual enjoying the dignity of a human being.

Industrial Relations deals with the stuff that dreams are made of: the apprentice school for the boy who yearns to learn a trade or gain an education; the professional training that makes the difference between a promotion, a career, or an unfulfilled ambition. Industrial Relations may mean the difference between life and death for an individual. This is the difference between a job well done in safety, or the pathos of visiting a man's home to tell his widow that on this dav she lost her husband, and the Shipyard lost a valued employee. It means endless hours of inspection for the leaky oxygen hose, or the frayed electrical cord, or the faulty rigging. It is the difference in finding them in time, or the consequence of not finding them until too late. Industrial Relations means even more. It means honesty, fairness, impartiality and objectiveness in the selection of the man best qualified for a job. It means a fair shake for everybody.

Industrial Relations includes the handling of the sick and troubled, protection for the abused, correction for the aggrieved, and punishment for the

offenders. Industrial Relations is the means by which the Navy recognizes its employees as human beings and individuals, and puts forth a friendly hand, an invitation for achievement.

There is no area of Industrial Relations which does not have its drama, its significance, because it deals entirely with human problems and human beings. Yet, of necessity, these elements are submerged in tomes of regulations, in endless forms and carbon copies, and in the tools and rules, and routine operations designed to handle the job.

The daily life of Industrial Relations deals with such prosaic things as hirings, firings, retirements, incentives and awards, disciplinary actions, hearings, appeals, safety regulations and inspections, training programs, and a host of related personnel actions. The volume of such work plus the regulations involved requires that each personnel problem be reduced to a format. It is guided by a standard, or a precedent. These conditions frequently inure the people who handle Industrial Relations to the point where they lose sight of the human or personal aspects of each case. In this situation the Industrial Relations Officer can make his greatest contribution to the organization. He has the job of evaluating each case, each action, to insure that the individual has been accorded every consideration under governing policies and regulations. He should determine that, in spite of the legality and accuracy of staff work, other viewpoints or fundamental principles have not been overlooked.

The Industrial Relations Officer has this responsibility not only to the individual, but also to the command. He must evaluate carefully the position of the command in each personnel action to insure that in spite of the correctness of management's action, there will be no adverse public relations aspects, or legitimate criticism of Command's action. This he must do without compromise of the principles and position that the Command must adhere to, and this he can do with human understanding. Human understanding is basically an appreciation and integration of such factors as individual rights, fair play, morale, protocol, timing, pride and sensitivity, local customs and mores, and the individual's health, well-being and security.

Individuals dealing in Industrial Relations must never forget that they are the administrators of a philosophy of government dedicated to the individual, his rights, freedom, life, liberty and pursuit of happiness. This philosophy has been promulgated by the will of the people, through Congress, into the very documents that guide their work.

If we accept the individual as the basic unit upon which to predicate Industrial Relations, the elements of a successful Industrial Relations program can be determined. What are the factors that motivate an individual? The individual seeks first *identity*—identity as a name, as a being, as a force and as a person. He seeks *Security*—security from an economic standpoint, security from a self-preservation standpoint, and security as an individual with the individual's rights. He also seeks something which may be called *Purpose*—purpose in himself as an individual, purpose in his relation to the organization, purpose in his relation to society and the community in which he lives.

Subordinate to these factors in individual motivation are the desires to achieve recognition, to earn esteem, to learn and understand meanings. The individual desires to grow and mature, to belong and cooperate, to defend himself against threats or danger, and

finally to achieve self-determination to exercise freely his identity, security and purpose.

Industrial Relations tries to meet these needs in a variety of ways. To satisfy the need for identity, the individual is indoctrinated to be a member of the team—the Navy team, the Shipyard team, the production, supply or planning team. He is identified by a personnel record, a badge, a number, a blood type. He wears a hat of special color to denote his trade, and sometimes his title. He has a grade or classification. He is identified, but by symbols only and he needs further identification. For his individual recognition, for his self-esteem, a program of awards and incentives is offered for good ideas, safe workmanship, good behavior, meritorious or outstanding contributions, safety and longevity. This program enables him to gain the individual recognition and self esteem that is essential.

For his security he is offered the protection of the civil service structure. He has appeal rights for grievances, and retention rights based on seniority, competitive status, longevity and veterans preference. He has promotional rights and prospects of future advancement. There are training opportunities to enhance his value to himself and the government. Personal security is afforded by a safety program, emergency medical care, a health plan, a pension and disability retirement plan, and a federal insurance program.

To give him purpose, he is enlisted in his country's defense, in the maintenance of its Navy. He is given pride in *his* work, *his* job, *his* shop, *his* Shipyard, *his* Navy. He feels his purpose in alliance with something bigger than himself to which he can devote his heart and soul, loyalty, efforts, and the sweat of his brow. As he progresses in his promotions, he finds security increasing, identification becoming more complete and unique. His purpose and meaning are ever expending. He is integrated as a whole man. Thus he becomes a useful productive employee and citizen, a bulwark in times of emergency, an asset in his daily work. This is the goal and the purpose of Industrial Relations. It produces a sound, healthy organization.

The value to an organization and its command in achieving such development on the broadest possible base cannot be questioned. But what are the telltale signs that measure the success of Industrial Relations? When an employee can relate and understand his own importance to the organization, the fundamental step has been achieved. When he knows that his days of sick leave are an increased cost to overhead, and understands that an increased overhead means the loss of productive work, he has arrived. When he is safety conscious enough not only to guard himself, but to remove safety hazards for others because he knows the personal suffering and cost of accidents, he knows the score. When he has found a better way to do a job, and so advises management, he's on the team. And when he buys savings bonds, he is putting in that extra bit of scrimmage that makes the team professional. It is Industrial Relations' job to teach him these things.

The reason that details such as sick-leave rates, safety records, beneficial suggestions, and bond participation are such important criteria of a command is that they all reflect morale. Morale is best gauged by the popular response of employees to the requirements of an organization. Satisfied employees have good morale, and boost the organization. All organiza-

tional strength is derived basically from employee satisfaction.

It is axiomatic among military organizations that a high degree of discipline and a high degree of morale go hand in hand. Disciplinary problems in a military organization staffed predominantly by civilians present a great challenge to military administrators. Many officers, in subordinate positions, gain the impression that discipline is a non-existent factor among civilian workers. They gain this impression not only because they see various infractions of rules going on unreprimanded, but also because they hear of disciplinary cases going through the grievance appeal channels at various stages. They know vaguely of employees' appeal rights to executive levels in Washington. They gain the impression that discipline is not only non-existent, but that it is non-enforceable. Like most impressions reached from fragmentary knowledge, this one is wrong.

Disciplinary action is provided for in Civil Service and Departmental Regulations. It varies in severity from letters of warning to separation, or removal of an employee. In addition, violations of various federal statutes provide for prosecution in federal courts, with penalties involving fines and imprisonment. There is indeed a solid foundation for disciplinary action to be taken against government employees. The concept, spirit and intent of disciplinary action under Naval Civilian Personnel Instructions is different, however, in that action taken should be the minimum possible to achieve corrective results. Civilian discipline is never considered to be punitive, and action taken is always predicated on the best interests of the government and the efficiency of the service. Disciplinary actions are frequently contested by employees in the exercise of their appeal rights. Obviously the lengthy hearings and procedures are costly to the government and to management. They pay for themselves however in the development of leadership, and in the corrective measures instituted by management as a result of the autopsy provided by the grievance appeal hearings.

Industrial Relations plays a vital role in the arena of disciplinary actions by insuring that the rights of both management and the individual are upheld and protected. Inevitably, Industrial Relations must make decisions, based on the findings of hearings and other evidence, as to the appropriateness of disciplinary actions. Having done so in council with his staff, the Industrial Relations Officer must advise the Commanding Officer and recommend command action. To do this properly, the Industrial Relations Officer must become Command's alter ego—weighing each problem from Command's viewpoint, as well as from the Industrial Relations viewpoint. His chief service is to inform command clearly and unequivocally of all aspects of a case, so that Command's decision can be reached with all factors considered. The execution of disciplinary action is one of Command's most important functions and responsibilities. It has a tremendous bearing on morale. The real trick in discipline is to balance the actions so that the offender is properly penalized; that, in non-separation cases, his value as an employee is not lost, and that supervision and the great body of law-abiding employees are vindicated or morally satisfied.

One of the anomalies of the personnel picture is that although we are in the machine age and the era of automation, manpower is of ever-increasing importance in any organization. In a liberalized sense, management

does not accomplish its mission with just things mechanical. Work is not accomplished with plant equipment alone. We all accomplish our jobs or missions with *people*. More and more we realize that manpower is our most priceless commodity. As such, it is essential that manpower be treated as an entity, and as a vital factor in industrial operations. We have also learned that people require a great deal of care and maintenance. To perform this care and maintenance is Industrial Relations' job.

The modern Industrial Relations Department did not spring full blown from some new concept or new discovery. It is the result of the evolution and integration of various functions that were performed separately, in the case of a shipyard, by each of the various departments. Centralized direction of these functions was necessitated by the unprecedented requirements of World War II, and the organizational growth of the Navy and its activities. In addition, the inter-relation of personnel procurement, training, communications, safety programs, employee relations, disciplinary actions and so forth indicate the obvious advantages to be gained by administering all such functions under one roof. Hence—the Industrial Relations Department.

Basically, Industrial Relations consists of three main factors. These are the Procurement of Personnel, Training of Personnel, and Communications of Personnel.

Procurement of personnel means more than just hiring. Mere hiring has its difficulties at the present time due to high employment levels in our expanding economy. Procurement of personnel means having the right number of employees at the right time with the proper qualifications to do the job. It requires skilled recruitment and selection of applicants, by means of examinations, evaluation of experience and qualifications and, in some cases, it involves security aspects. Procurement of personnel depends to a considerable extent on the reputation of an organization. Various surveys have indicated that pay alone is not the governing nor most important criterion to most job applicants. Security and a happy employee climate are two leading factors that influence employees. Good Industrial Relations helps to create those factors.

Training is one of the two most important keys to the personnel picture. Training increases individual capacities and opportunities, and unlocks reservoirs of manpower that would be otherwise unavailable. Continued training at supervisory and management levels, as well as at the apprentice and journeyman levels, is essential to the growth and productivity of an organization. Technical progress and manpower shortages have both emphasized the importance of training.

Communications is the other key. Getting the word across is essential not only to insure that orders and line functions are carried out, but also to insure a means for management to enlighten personnel with respect to policies and objectives. Communications with employees is necessary in the never-ending task of interpreting management's role as a vital, active, beneficial force. It is equally important to management or command to have a channel by which the employees' thinking can be made known to top levels.

Other factors which are essential to an effective personnel program include:

A. A Safety Program—to conserve

our precious commodity, manpower.

B. A Health or Medical Aid Program — again essential to save life, or to restore personnel to maximum capacity in the least possible time.

C. A Promotion Policy—to attract talent and keep it stimulated.

D. A Retirement Program—to reward loyal service and provide for future security.

E. An Awards and Incentive Program — to stimulate employee morale and reward talent.

F. A Disciplinary Policy—to cope with the human problems that are always with us.

G. An enlightened Employee Relations Program, which embraces not only employee or labor group recognition, but provides essential employee services. These employee services may include a host of things, such as transportation, housing, parking, food services, insurance programs, credit union operations, legal advice, and social activities.

These programs are all aimed at the one objective desired by both management and the employee: job stability. Stability results from employee satisfaction. Satisfied employees are productive partners on the Management-Labor team.

Today Navy's industrial complex enjoys the organizational strength, the employee stability, satisfaction and productivity necessary to do the job. The Chief of Naval Operations may proceed with confidence on the Navy's mission. Industrial Relations is doing its part of the job.

COMPARISON OF WELDED AND RIVETED SHIP CONSTRUCTION

ACKNOWLEDGEMENT

This article, published in the 22 July, 1955, issue of *Engineering*, was written by B. Baxter.

In the early part of 1943, and while the Admiralty were increasingly encouraging the use of welding in the construction of ships being built in British shipyards, reports of failures in welded ships built in the United States were being received. The most outstanding and startling was the case of the all-welded tanker *Schenectady* which, for no apparent reason, broke in two on January 16, 1943, while tied alongside a quay at Portland, Ore. Although we had had no similar troubles it was clear that if United States welded ships had failed, British welded ships might fail also and the subject therefore demanded close consideration.

In June, 1943, at the instigation of the First Lord of the Admiralty, the Admiralty Ship Welding Committee was set up with terms of reference as follows: "To consider and investigate special problems arising from the employment of welding in ships' structures and to advise on methods for their solution." A working committee known as the Admiralty Ship Welding Sub-Committee was also appointed and included on this were representatives of Admiralty departments, Classification Societies, and Welding Research Council and later the British Shipbuilding Research Association.

One of the main investigations carried out by the Committee and Sub-Committee was to find the relationship, if any, between welded ship failures and design, with particular reference to the differences in structural behavior between riveted and welded ships. It had been established that the scantlings of all the welded ships in which structural casualties had occurred did in fact, comply with the Classification Society requirements for riveted ships, and that no scantling reduction had been made because welding had been used.

Because quantitative knowledge on the structural behavior of riveted ships was scanty, the problem of finding the differences between riveted and welded ships could only be tackled by the use of fundamental principles. New methods and instru-

ments had to be developed which would accurately enable stress distributions under service conditions to be found, and existing theories had to be examined critically in order to ascertain their suitability as a basis for comparison.

Statical strength experiments on such ships as the *Empire Duke, Neverita* and *Newcombia* provided very useful information, but after a preliminary test on the tanker *Niso* at sea it became clear that a great deal still remained to be learnt about the behavior of a ship's structure under dynamic conditions.

PROGRAM OF STRUCTURAL TESTS

In comparing the structural behavior of riveted and welded ships at sea it at first appeared practical to send to sea ships of similar form and structural design, one being riveted and the other welded, and to measure the stresses on each simultaneously. On close examination, however, this proposal presented serious difficulties. No matter how closely the two ships sailed together they would be unlikely to encounter the same wave conditions. During rough weather, when the results would be of maximum importance, the discrepancies would be greater as the distance between the vessels would have of necessity to be increased. After very careful consideration, therefore, the Committee decided to proceed as follows:—

(1) The *Ocean Vulcan,* a 10,000-ton dead-weight all-welded standard dry-cargo ship built in the United States to the order of the Admiralty, was to engage in its normal trading on the North Atlantic route for at least twelve months. During this period a very complete record would be kept of the various types of forces, weather conditions, wave particulars, frequency of stress occurrences, etc., to which the ship was subjected.

(2) The *Ocean Vulcan* was to be subjected in still water to all the different types of forces likely to be met with at sea. These forces would include bending, shearing, and torsion. The corresponding stresses and deflections produced would be measured.

(3) The *Clan Alpine,* an all-riveted ship closely similar to the *Ocean Vulcan,* would be subjected in still water to the same forces as the *Ocean Vulcan* in still water. The results of the trials in still water on both ships would then be applied to the probable maximum loads as derived from the sea trials in order to estimate the maximum stresses at sea for both the riveted and welded ships.

This procedure was adopted and the results of the various trials have been published by H. M. Stationery Office for the Admiralty Ship Welding Committee with the Authority of the Lords Commissioners of the Admiralty. The reports relating to the trials are:—

R.6 *Ocean Vulcan.* Still Water Experiments.

R.7 *Clan Alpine.* Still Water Experiments.

R.8 *Ocean Vulcan.* Sea Trials.

R.9/10/11 *Ocean Vulcan.* Sea Trials. Detailed Analyses.

R.12 *Ocean Vulcan* and *Clan Alpine* Structural trials. Discussion of Results.

The dimensions of the two remarkably similar vessels are:—

Length overall, 441 ft. 6 in., *Ocean Vulcan* and *Clan Alpine.*

Length between perpendiculars, 416 ft. 0 in., *Ocean Vulcan* and *Clan Alpine.*

Depth Molded, 37 ft. 4 in., *Ocean Vulcan* and *Clan Alpine.*

Beam Molded, 56 ft. 10¾ in., *Ocean Vulcan;* 56 ft. 11¾ in., *Clan Alpine.*

OCEAN VULCAN SEA TRIALS

The *Ocean Vulcan* sea trials commenced on December 29, 1945, and lasted through eight round voyages until May 19, 1947. During all this time records were taken by gauges fitted on the outside of the hull around twelve transverse sections, and these measured water pressures and wave profiles.

Other readings taken included:—

1. Accelerations of the ship.
2. Wind forces on exposed hull.
3. Angles of roll, pitch and yaw.
4. Engine speed and shaft torque.
5. Ship speed.
6. Longitudinal stresses near amidships.

All the instruments and gauges were connected to one central control room having the indicators and meters mounted on one large panel. This panel was photographed twice every second with a special camera.

Additional measurements included:—

7. Stereoscopic photographs of waves.
8. A statistical strain gauge.

This combined information was sufficient to obtain values for the probable maxima of the various types of loading forces such as shearing and bending in both the vertical and horizontal planes, twisting and transverse bending, and the combinations in which they occurred.

STILL WATER TRIALS

The primary object of the static trials which took place during 1946, 1947 and 1948, was to study the stresses set up on a section near amidships by known changes in the applied bending moments, and also to measure the deflections of the main hull due to these changes. The tests were so planned that each of the following actions could be isolated:—

(a) Vertical longitudinal bending moment.

(b) Vertical longitudinal shear force.

(c) Horizontal longitudinal bending moment and shear force.

(d) Torsion moment.

(e) Longitudinal compressive action.

(f) Transverse bending due to change in draft.

Secondary aims were to measure local stresses and unfairness of plating.

The changes in the bending moments were caused by flooding the water ballast tanks and holds to predetermined depths.

The gauges used to measure the strains were:—

(1) Electric resistance strain gauges, less than 1 in. base length.

During the static trials on the *Neverita* and *Newcombia* the electric resistance strain gauge readings were not used in the final analysis because of zero drift errors. In the present experiments, however, the difficulties had been overcome, and no drift was apparent over a period of several weeks.

(2) Building Research Station acoustic gauges, 3¾ in. base length.

(3) Maihak acoustic gauges, 5 cm. and 10 cm. base length.

These gauges were of the same type as those used in the static trials on the destroyer *Albuera* (I.N.A.* 1952).

(4) Long base gauges, 100 in. base length.

A theodolite capable of reading to 1 second of arc was used to measure the deflection of the ship by observing the movements of fixed targets spaced along the upper deck. Such a theodolite would be capable of reading a movement of approximately 0.01 in. at a distance of 200 ft.

* Transactions of the Institution of Naval Architects.

Fifty copper-eureka thermocouples, capable of reading a difference of 1 deg. F. were used to show temperature variations during the trials.

GENERAL CONCLUSIONS

The investigation found that the differences in structural behavior between the riveted and welded ships are of a secondary character and are related to details of design rather than to overall structural performance. This general conclusion confirms the results of the earlier experiments carried out in 1944 and 1945 on the similar tankers *Neverita* (I.N.A. 1946) and *Newcombia* (N.E.C.I.† 1946).

The conception, execution and presentation of the work contained in the Reports forming the Series R.6 to R.12 is on a very high plane. Nothing very revolutionary has been discovered as a result of these trials, and in fact the answers to many problems were suspected before the problems were tackled. However, throughout these trials every possible aspect, practical or theoretical, has been considered and the conclusions are based firmly and confidently on the latest available theoretical considerations and refinements. Where approximations have been made the assumptions justifying the step have been shown and commented on. Anticipating that future workers and theoreticians will either be aided by new theories, or will use a different approach to the problem, the Report very wisely includes, wherever practicable, the actual measurements taken.

The mass of experimental work and the arduous computation involved was prodigious, and the various analyses were so planned that the necessary arithmetical operations could be performed by intelligent, but non-technical staff. All who have had the opportunity of guiding or contributing to this fine piece of work, rightly deserve the thanks of naval architects and engineers for their solution to a difficult and complicated problem. The conclusions at the end of Report R.12, and given below, contain much of interest and importance, and are worthy of close examination, particularly with regard to the sea trials where much new statistical information has been made available.

(1) "Provided due allowance is made for the effects of stress concentrations, local bending and the inefficiencies of panels of plating due to unfairness, the distribution of longitudinal stresses was similar in the two ships examined, and in fair agreement with simple beam theory."

The efficiency (η) of any piece of plating is defined here as the actual heart of plate strain divided by the frame strain. Neglecting the transverse stress the heart of plate stress in the longitudinal direction is η times the stress which would occur at the same point in a plate with 100 per cent efficiency, i.e., one in which there was no distortion out of the plane. Similarly, the contribution of any piece of plate of cross section A towards the overall moment of inertia is reduced to ηA. The efficiency in some cases was found to be low, and in the second deck of the *Ocean Vulcan* efficiencies as low as 20 per cent were observed. The net effect of reduced plate efficiency was to reduce the effective moment of inertia by about 10 per cent.

In static trials on the U.S.S. *Philip Schuyler* (A.S.N.A.* 1947) the 'tween deck and tank top plating were found to be only 50 per cent efficient. Ac-

† Transactions of the North East Coast Institution of Engineers and Shipbuilders.

* Transactions of the Society of Naval Architects and Marine Engineers (U.S.A.).

counting for this reduced the moment of inertia of the section by 5 per cent.

Clearly, the stress as forecast using the simple beam theory: $\frac{My}{I}$ can only be used for panels of plating whose efficiency is 100 per cent. In consequence, for all points at which the buckling of the plating is prevented by longitudinal stiffening, the stresses will be higher than those given by the simple theory.

The stress observations made suggest that the application of Lockwood Taylor's theory of shear lag (N.E.C.I. 1924) is complicated in the case of a dry cargo ship by the presence of large deck openings.

(2) "No evidence was found to indicate that the presence of riveted seams affects the general distribution of longitudinal stress."

(3) "Concentrations up to about three times the nominal stress were found at structural discontinuities, with a tendency for the concentrations to be slightly greater in the welded than in the riveted ship."

This concentration of stress has been noted in many previous trials (A.S. N.A. 1949), e.g.:—

	Stress factor
Neverita.	
Bulwark rails and small hatchways	1.25—1.6
Newcombia.	
After end of bridge	2.0
around hatchways	1.6
Philip Schuyler.	
Original hatch corners	2.0
Corners of house structure.	1.5
President Wilson.	
Bulwark plating	4.6

(4) "The inefficiency of plating due to unfairness had the effect of reducing the effective moment of inertia and shifting the neutral axis, thereby modifying the stress distribution. In addition, the stresses in the vicinity of longitudinal stiffening were increased by the unfairness of the plating."

(5) "Apart from the eccentricities which occur at over-lapped joints, the initial unfairness was found to be greater in the welded than in the riveted ship."

This unfairness was also found to be true in the case of the welded tanker *Neverita* and the riveted tanker *Newcombia*. The panels of plating in the riveted ship have the benefit of the stiffening influence of the riveted overlaps.

(6) "Although the heart-of-plate stresses in the unfair plating were usually lower than those which would have occurred in the same plating if it had remained plane, the surface stresses were often higher owing to the effects of local bending."

(7) "In the case of the welded *Ocean Vulcan* the unfairness was at some places such that the combined local bending and heart-of-plate stresses were sufficient to cause local yielding of the material, which increased the unfairness."

(8) "No significant difference was found between the flexural rigidities of the welded and riveted ships. In the particular cases examined, the welded ship had slightly the greater flexibility."

AGREEMENT BETWEEN THEORY AND OBSERVATIONS

(9) "Agreement between the theoretical and observed values of deflection in the two ships examined was obtained after taking account of superstructures, local inefficiencies of unfair plating, discontinuous members and other such effects."

The observed deflections in both

ships, after being corrected for temperature effects, were about 10 per cent greater than the theoretical.

The total deflection was given by $y = y_b + y_s$.

That due to bending y_b was calculated using:—

$$y_b = \int \frac{M}{E\,I} dx\,dx$$

where I = moment of inertia of all the continuous material in the section except deck erections, M = bending moment, and E = Young's modulus.
The shear deflection was calculated from the approximate formula:—

$$y_s = \int \frac{F\,L}{A\,N},$$

where A = web area only of the section, F = shearing force, L = length of the section, and N = shear modulus.

This formula was used for ease in calculation rather than the more exact, but more laborious form propounded by Lockwood Taylor, in his shear lag theory, i.e.,

$$y_s = \frac{1}{n} \int\int w \int y \int \frac{m}{24\,I^2\,t}$$

Using the latter will give an addition of about 1 per cent in the total deflection.

The temperature deflections averaged about ⅛ in. and it was calculated that the theoretical temperature deflection for both ships would be 1 in. for 22 deg. F. difference of temperature. In the case of the *Neverita* it was observed that the ship hogged by about 1 in. when the rise in air temperature exceeded the rise in sea temperature by 24 deg. F. However, if it is assumed that temperature deflections result from the unrestricted expansion of the upper deck relative to the bottom then the calculated value would be 1 in. per 16 deg. F. This implies that the partial restriction of free thermal expansion by attached structural members not having the same rise in temperature reduces the overall calculated temperature deflections by about one-third.

In the static trials on the destroyer *Albuera*, the calculated temperature deflection, using Hurst's method (I.N.A., 193), was 1 in. per 18 deg. F.

(10) "No conclusive evidence of rivet slip in the butts or seams was found within the range of bending moments and shear forces applied during these experiments, but the lower stress concentration factors found in the riveted ship suggest that rivet slip may have occurred in the vicinity of discontinuities."

MAXIMUM RANGE OF BENDING MOMENTS

(11) "The maximum range of bending moments at sea cocurs when the ship's course is normal to the wave crests, and when the wave length is approximately equal to the ship's length."

This conclusion is borne out by other experimenters, particularly Schnadel in the San Francisco trials of 1934 (I.N.A., 1938).

Calculations for the vertical bending moments were made using wavelengths varying from l = 0.4 L to l = 2.0 L, where L is the length between perpendiculars, and the heights of the waves used were obtained from a formula derived from a thorough analysis of wave heights collected from all available sources, i.e.:—

$$h = 24\,(1.0 - e^{-\frac{l}{200}}) + \frac{l}{30},$$

where h is the upper limit of wave height for any wave, in feet, and l is the length of the wave in feet.

The calculations were made for three different loading conditions in-

volving changed displacements, and the waves were assumed to be normal to the ship's length. It was shown that the wave bending moment ranges were largely independent of the loading, and the maximum value of 255,000 tons-feet occurred when the wave length and ship's length were approximately equal. This bending moment gives a stress range in the top of the sheerstrake of 11 tons per square inch. However, if a standard $\frac{L}{20}$ wave were used, then the most severe waves would have a length of 1.2 L. It was also found that the standard strength calculation, neglecting the Smith correction, gives a range reduction of 35 per cent in the loaded condition, and 20 per cent in the light condition.

The Smith correction (I.N.A., 1883) is made in order to take account of the fact that there are variations in the fluid pressure in a wave form due to the circulation of the particles of water.

(12) "When the ship is inclined to the direction of the wave advance, horizontal bending moments arise, the magnitude of which, under certain conditions, may exceed those of the co-existing vertical bending moment."

(13) "The maximum combined stress effects of the vertical and horizontal bending moments do not exceed, at the gunwale and the bilge, the highest value for the vertical bending alone. The combined effects do, however, influence the maximum stresses in the side plating."

(14) "Stresses caused by axial compressive forces are only a small percentage of those caused by the maximum vertical bending moment."

(15) "The stresses caused by the torsional forces due to wave action may be neglected."

MAXIMUM WAVE HEIGHT

(16) "For waves not longer than 800 ft., the maximum wave height, within the bounds of practical probability, may be expressed by the formula:—

$$h = 21.5(1.0 - e^{-\frac{l}{200}}) + \frac{l}{33},$$

where h is the height of the waves in feet and l is the length of the waves in feet.

The above formula, which gives a wave height equal to 90 per cent of the maximum possible wave height, is based on evidence collected from a statistical strain gauge fitted during the *Ocean Vulcan* sea trials and on additional oceanographical information. From this it appeared that a range equal to 80 per cent of the maximum possible bending moment range may be expected once within 10 ship years, and 90 per cent of the maximum once within about 1,000 ship years. This is shown in Fig. 1.

The use of this formula would give a height of 31.5 ft. for a wave of length equal to the *Ocean Vulcan* (L.B.P. = 416 ft.), i.e., a ratio of length to height of 13.2. This is considerably greater than the ratio of 20 that is used in the standard strength calculation, which would give a wave height of only 20.8 ft.

(17) "Theoretical and experimental evidence indicates that in the equations which relate the motions of a ship among waves to the resulting bending moments the dynamic terms tend to cancel each other, and only become important under conditions of resonance, which, however, are unlikely to occur under severe wave conditions."

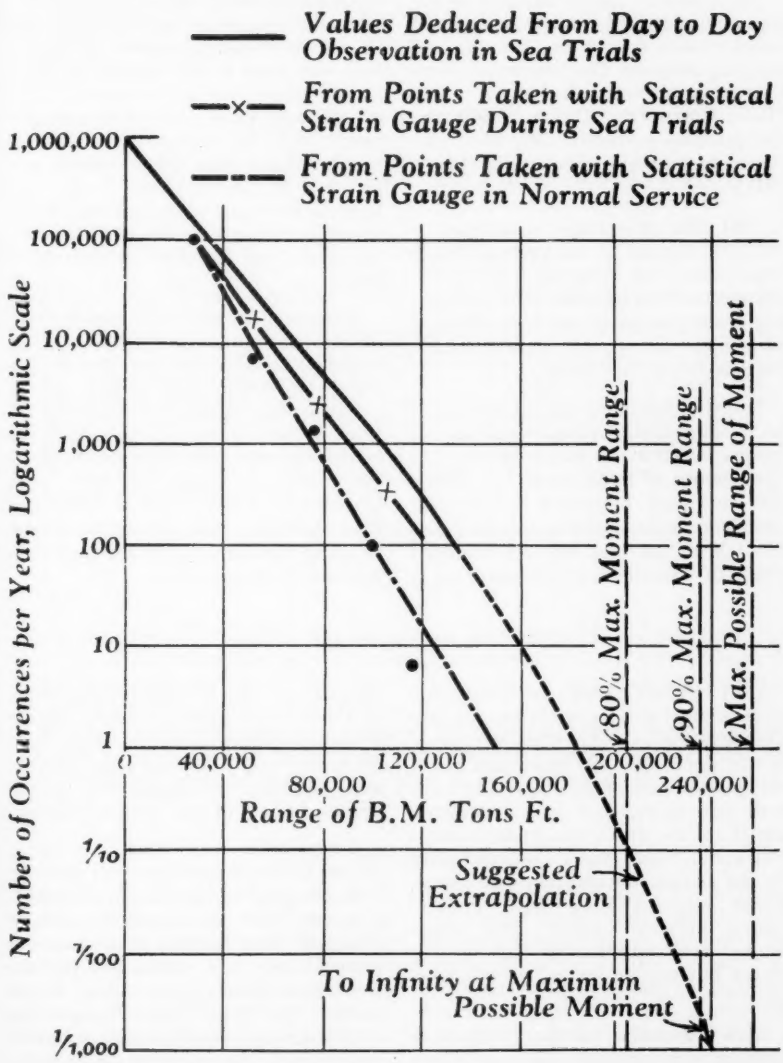

Figure 1. The ranges of bending moment in tons-feet are plotted against the number of occurrences per year. A range equal to 80 per cent of the maximum possible bending moment is likely to occur once in 10 ship-years.

The dynamic forces referred to are those caused by the accelerations and decelerations due to the heaving and pitching motions. The heaving correction is sometimes referred to as the "Read Correction" (I.N.A., 1890) and the pitching correction has been extensively studied by Alexander (I.N.A. 1911).

(18) "For the ships considered, a reliable estimate of the vertical bending moment due to waves of any given dimensions may be obtained by assuming the ship to be in static equilibrium on a trochoidal wave form, and applying the Smith correction."

The addition of the Smith correction to a standard strength calculation means a relatively large increase in the amount of work needed to obtain the corrected buoyancy curve. The justification for omitting this at present lies in the fact that all standard strength calculations are used on a comparative basis and are not intended to derive actual stress values for the assumed loading conditions. Therefore, any error is not material as along as it is perpetuated in all similar calculations, and the derived stresses are used only for comparison between similar ships. One other reason put forward for its omission is the fact that the inclusion of the correction reduces the value of the maximum bending stress, and therefore the margin of safety.

However, there is now justification for the assumption that the theoretical calculation, with the addition of the Smith correction does, in fact, give a realistic value to the stresses as measured at sea. It would, therefore, be advantageous to calculate the value of the Smith correction for each ship. Champness showed (I.N.A. 1928) that the reduction in the maximum statical bending moment for a 400-foot ship was about 15 per cent.

SLAMMING STRESS

(19) "Slamming was not extensively investigated because of the unsuitability of the experimental equipment. It was noted that the maximum slamming stress amidships was about $\pm 1\frac{1}{2}$ tons per square inch at a frequency equal to the ship's two node vertical vibration. Slams were observed only in the ballasted condition and numbered approximately 2,000 in one year's normal service. The stress caused was additive to the sagging stress but not in general to the hogging."

The correlation of the stress to a frequency of vibration has been noted by many experimenters, and the question of impact stress is one which has given rise to much experimental work in the United States. Another factor of considerable importance is the duration of impact, and the phase difference between the application of the impact force and the vibrating body.

It is possible that, during slamming the period between slams will coincide with the pitching period. If, therefore, a second slam occurs at the proper phase of the vibration cycle then the impact loads and stresses caused by the second slam may be added to the residue left by the first. These forces may build up until a fracture or buckle occurs, probably at some discontinuity, and in the limit such a fracture may lead to the loss of the ship.

MODEL TEST ON A STEAM TURBINE INLET VALVE

JAMES H. POTTER

THE AUTHOR

was born in the City of New York and was trained in engineering at Columbia and Johns Hopkins Universities. In addition to five years in the chemical and shipbuilding fields, he has had fifteen years of experience in research and teaching at the university level. He has had academic assignments at Johns Hopkins University and at the University of Illinois. Since 1953 he has been Head of the Department of Mechanical Engineering at the Stevens Institute of Technology. He has been a member of A.S.N.E. since 1939 and has contributed two other papers to the JOURNAL.

SUMMARY

As a drafting room exercise, a steam turbine inlet valve was designed for which the area of the steam flow passage increased linearly with the lift of the valve stem. Three geometrically similar models of the valve were made and tested in the steam laboratory of the University of Illinois.

Weighed condensate readings exceeded the theoretical steam flows in nearly all cases, even after due correction had been made for supersaturation. Discharge coefficients are reported over a wide range of valve lifts and for several back-pressures.

INTRODUCTION

Modern practice has tended toward a steam turbine inlet valve which is composed of a mushroom type plug seating against a rounded entrance orifice which may be followed by a divergent section. This design has been the result of an effort to streamline the inlet valve, minimizing shock and pressure drop losses.

In an effort to meet these requirements and also to obtain a design giving a linear relation between valve lift and flow area, several mushroom and nozzle combinations were laid out. One such design is shown in Figure 1. Here all of the dimensions are related to the throat diameter of the nozzle. The mushroom makes closing contact on a diameter larger than the throat diameter of the nozzle. When the valve is open, the theoretical flow area between the mushroom and seat is the lateral area of the frustum of a right circular cone having the same axis as the valve stem. As the lift is increased, the mean diameter of the conical frustum de-

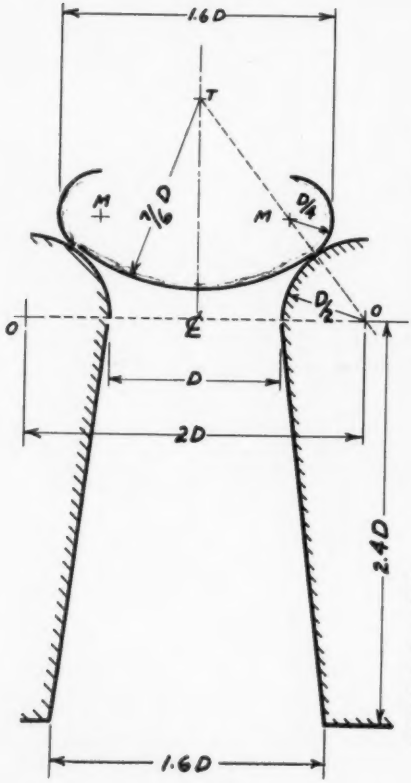

Figure 1

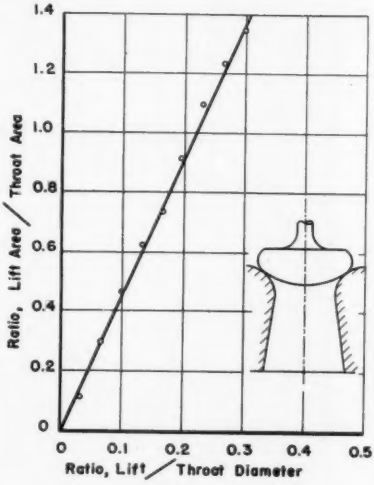

Figure 2

creases. The flow area therefore varies as a combination of increasing slant height and decreasing mean diameter.

The dimensional configuration shown in Figure 1 was laid out to very large scale on a drawing board. The theoretical flow area was computed for a number of lift positions. The calculations indicated that there was an almost linear increase of flow area with lift. The results have been plotted as dimensionless ratios in Figure 2.

The research upon which this paper reports consisted in the construction and testing of three geometrically similar valves conforming to the dimensional pattern of Figure 1. Small sizes and moderate steam conditions were imposed by the limitations of a college laboratory.

DESCRIPTION OF APPARATUS

Nozzle plates were made of mild steel for throat diameters of ¼, ½ and ¾ inches. The corresponding mushrooms were also turned from mild steel and each had a six inch valve stem. The nozzle plates and valves are shown in Figure 3. The nozzle plates were equipped with four ¼ inch studs for attaching to the test chamber.

Great care was taken in the alignment of the valves and in the instru-

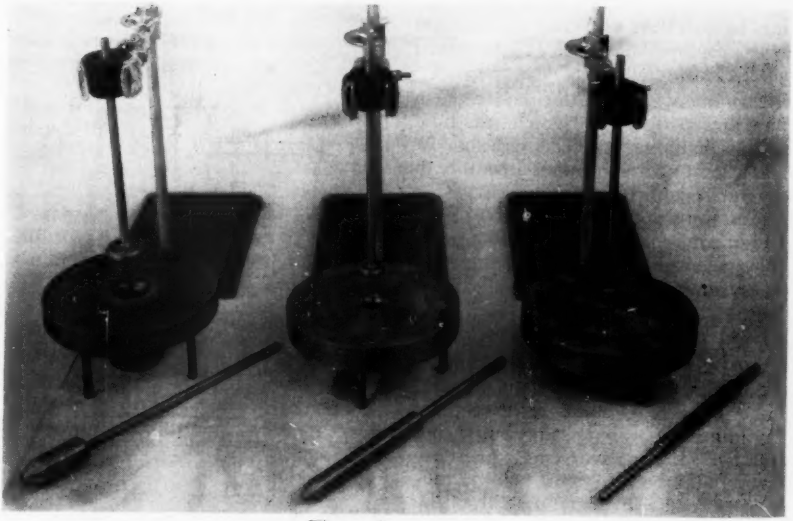

Figure 3

mentation for the experiments. In Figure 4 a valve is shown in place in the test chamber. The pressure vessel was made from a six inch cast steel tee with a two inch side opening. The flanges were faced off, and special cover plates were made for the two ends. The lower cover plate was bored out to accommodate the end of the nozzle plate; also four oversize holes were drilled in the lower plate, through which the nozzle plate studs protruded. In setting the nozzle plate a special mandrel was used. The mandrels are shown in Figure 3. The mandrel replaced the valve stem and centered the nozzle plate on the bottom cover plate. The nozzle plate studs were then tightened from below. The mandrel was then replaced with the valve stem.

To prevent displacement or vibration of the valve stem assembly, Figure 4, the sleeve M was made to act as a crosshead guide. This sleeve consisted of a length of one inch pipe with a cover plate welded in the end. It extended almost to the nozzle plate. Nor-

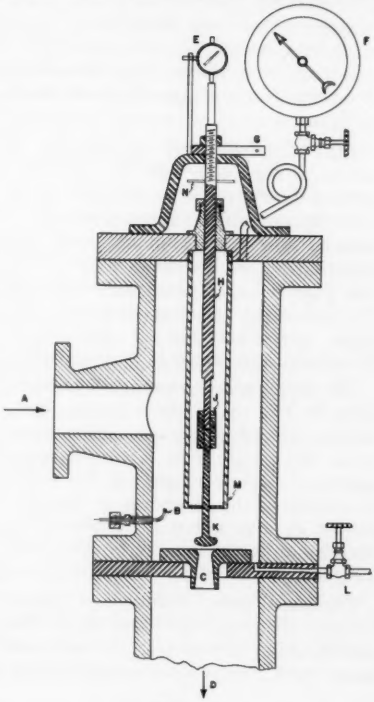

Figure 4

mal to the steam entrance leg, A, a slot was provided in the sleeve to afford access to the coupling, J.

The main shaft H, terminated in a fine threaded section which was held in the clamping nut G. A crossbar N, was used to turn the stem assembly in the nut. A calibrated dial gage E, rested on the top of the stem assembly. Both an indicating, F, and a recording pressure gage was used. A drain connection was provided at L.

Three thermocouples were located at 120 degree intervals near the lower end of the tee. They were made from chromel-alumel wire, and were calibrated against a standard Platinum-Platinum Rhodium thermocouple in a standard bath. Over the operating range of temperatures the test thermocouples read within one percent of the calibrating thermocouples. The thermocouples were installed in copper tubing, bent upward to prevent interference with the internal assembly. One such thermocouple is shown at B in Figure 4.

The principal test equipment is shown in Figure 5. The chamber described on Figure 4 is represented as D in Figure 5. The superheated steam entered the system at A, and was throttled by the valves B and C. The dial gage R, established the valve lift. The indicating and recording pressure gages are shown at N and O. A throttling calorimeter S, was available.

The test chamber rested on a six inch cross F. The cover plates on the cross were removed when the nozzle plate studs were tightened. The backpressure was read on the gage P. The valve G connected the discharge to the condenser H. The pump J, conveyed the condensate to the tank K where it was weighed.

The panel board is shown in Figure 6. Only the right side was used. The test chamber is obscured by the panel board itself. The indicating and recording gages are shown, with the thermocouple ice junction, selector switch, valving and potentiometer. All of the pressure gages were calibrated against

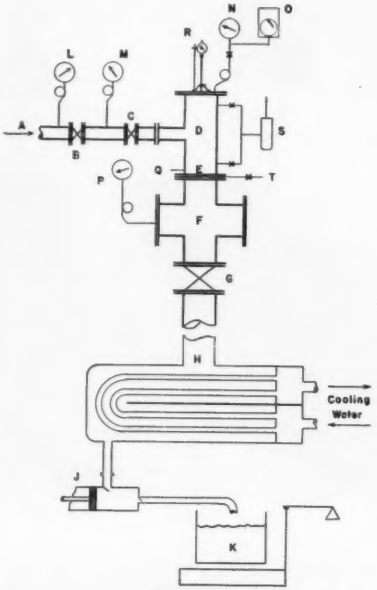

Figure 5

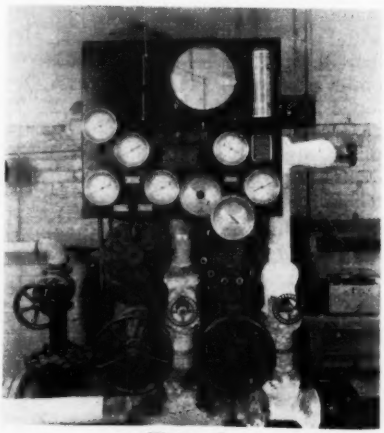

Figure 6

a deadweight tester. The dial gage was checked against Johannson blocks over the operating range.

The following procedure was used to check the steam tightness of the test valves: With the valve seated, the upstream pressure was brought to 50 psig, then one of the cover plates on the cross, F, (Figure 5) was removed. In each case the valve was fully steam tight.

METHOD OF TEST

Preparatory to each run, the inlet conditions were set at 50 psig with about 300 F. TT. The valve was opened fully, and the backpressure was brought to 25 psig. The unit was kept at these conditions for more than an hour in order to bring the system to thermal equilibrium. The valve was then seated and the dial gage reading noted.

Maintaining the same pressures above and below the valve, a series of runs were made at varying valve stem lift. After completing such a series of observations, the backpressure was progressively raised to 30, 35, and 40 psig. In all runs the inlet pressure was maintained at 50 psig.

The condensate was weighed at regular intervals to determine the actual weight of steam passing through the test valve.

CALCULATIONS

The range of steam conditions available in the laboratory presented a severe limitation to the test work, restricting the steam pressures and temperatures. Also the exit conditions fell in the range where supersaturation was present. It has been shown that an isentropic expansion into the Wilson zone can be represented quite accurately by:

$$P_1 V_1^{1.3} = P_2 V_2^{1.3} \ldots\ldots (1)$$

Also the enthalpy change through the test valve can be expressed as:

$$\Delta h = \left(\frac{1.3}{1.3-1.0}\right)\frac{144}{778}(P_1V_1 - P_2V_2) \ldots (2)$$

The theoretical velocity was obtained from:

$$\overline{V}_2 = 223.8\sqrt{\Delta h} \ldots\ldots (3)$$

In any given run, all of the steam flows were corrected to the same initial temperature, for which the absolute pressure and specific volume were determined. Using equation (1), the terminal specific volume was found for a given back pressure. From equations (2) and (3) the theoretical discharge velocity was computed.

From Figure 2 the actual lift area was found for a given test valve and stem lift. This area was used in the continuity equation to find the theoretical steam flow:

$$W_t = A\,(\overline{V}_2)/v_2 \ldots\ldots (4)$$

The measurements of time and weight of condensate gave the data from which the actual steam flow, W_a, was computed.

The discharge coefficients, C_d, were found from:

$$C_d = W_a / W_t \ldots\ldots (5)$$

DISCUSSION

The discharge coefficients for the three valves are shown plotted against the ratio L/D in Figures 7, 8, and 9. In all cases the minimum discharge coefficient was found at L/D = 0.22, the stem position for which the flow area was equal to the throat area. Minimum C_D also approached unity. Numbers on the individual curves represent backpressure, psig.

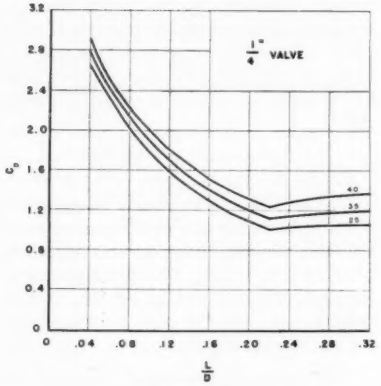

Figure 7

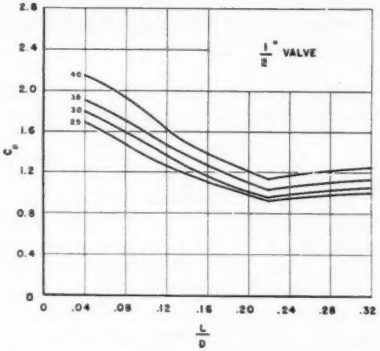

Figure 8

The explanation for the very high discharge coefficients rests partly with the test technique and partly, with the method of calculation. At small L/D the mushroom is close to the valve seat. The mushroom and seat constitute a convergent-divergent nozzle in which the steam attempts to expand to the critical pressure. As a result the flow rates are greater than if the test back pressure were effective. The steam pressure falls to or near to the critical pressure then builds up again to the regulated backpressure. This is a phenomenon widely observed in De-Laval type nozzles. Apparently when the lateral flow area is equal to the throat area the assembly is least like an expanding nozzle.

Beyond L/D = 0.22 therew as an increase in discharge coefficient in all cases. This may be explained by the fact that the valve seat becomes active as a DeLaval nozzle, and the effect of the mushroom decreases. What probably happens is that as the lift increases the inlet pressure becomes more nearly uniform and equal to 50 psig. The discharge coefficients for L/D = 0.22 appear to trend asymptotically toward constant values.

The wide range of C_D for the three valves is explained by geometric considerations. The smaller the mushroom the greater the difficulty in machining it to exact dimensions. Here also, a small departure from design might have a larger effect on the measured steam flow. Also the smaller the valve the greater the effect of a weighing error on the actual steam flow. The combination of the foregoing effects are brought out in the graphs, Figures 7, 8, and 9.

The geometric effect is apparent in another respect. For a given L/D ratio the change in C_D is a function of the overall pressure difference across the assembly. For example at L/D = 0.22:

Valve Size Inches	$\left(\frac{C_D @ 40}{C_D @ 35}\right)$	$\left(\frac{C_D @ 40}{C_D @ 30}\right)$	$\left(\frac{C_D @ 40}{C_D @ 25}\right)$
¼	.903	...	.813
½	.903	.838	.812
¾	.914	.854	.816

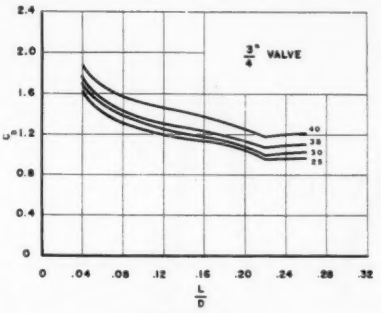

Figure 9

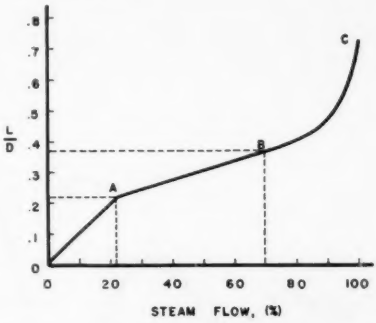

Figure 10

It is very difficult to relate the performance of an inlet valve on a steam turbine to this "test-bench" type of experiment. For one thing a turbine under the control of a single valve has a varying bowl pressure due to variation in speed and load as opposed to the constant backpressure conditions maintained in these experiments. As the test valve was built to a special design, it could not be exactly matched in a prototype.

However, a most interesting inference may be drawn from Figure 10. This represents the relationship of L/D to steam flow for a large steam turbine under the control of a single inlet valve. For convenience the steam flow has been presented on a percentage basis.

Lost motion or expansion allowance accounts for a small valve stem movement before steam flow is started. A linear flow-lift relationship obtains from this point to the point "A," for which $L/D = 0.219$. There is no guarantee that this represents the point of equality between the flow area and throat area. However, the area ratio is probably close to unity.

From "A" to "C" the lift is increasing but the backpressure is increasing also and the flow rate continues to rise. It is probable that the mushroom is not effective in the extreme right hand portion of the curve and that the flow rate is controlled solely by the backpressure and the configuration of the nozzle.

CONCLUSIONS

The research presented in this paper is preliminary in nature. Refinements in test technique would probably result in more consistent data from which more could be learned. However, any extension of the work should be done in a turbine manufacturer's plant, rather than a college laboratory.

The author would welcome an opportunity to build a larger model which could be bench tested and then tested in a steam turbine.

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation for the painstaking care exercised by Mr. D. G. K. Reddy of Madras, India. Mr. Reddy, then a graduate student in Mechanical Engineering, took most of the measurements and made many of the improvements in the apparatus.

Thanks are also due Dr. L. N. Tao, of the Illinois Institute of Technology, who examined the data.

CREATIVITY

ACKNOWLEDGEMENT

This reprint consists of two articles recently published in the *General Electric Review*. Part I, which was written by E. K. Von Fange, appeared in the July, 1955, edition, and Part II, written by C. F. Hix and D. L. Purdy, appeared in the May, 1955, issue.

PART I

UNDERSTANDING THE CREATIVE PROCESS

Literature on the subject of creativity reveals some confusion and uncertainty as to its meaning. Few writers say whether creativity is a product of heredity or environment, usually giving a ratio of one line of statement to 20 lines of qualification.

Creative men in the past are usually portrayed as receiving some mysterious illumination, or inspiration—sometimes referred to as a "flash of genius" — to climax their creative search, often appearing to them in the dead of night. Thus from study and practice, a novice might expect to be suddenly awakened by a flood of illumination and, in a brilliant flash of genius, spout forth his first creation.

With creative ability placed on such a high pedestal, it may now disturb people to see it also applied to homemaking, gardening, art, and other areas. And so let's ask such basic questions as: Who is creative? is it the man who proposed the basic idea or the people who carried through the development and design and made it practical? was the end device even a creation? if so, were the contributors each partially creative, ingenious, or not creative at all?

Today's student of creativity is appalled when an experienced engineer coldly and logically proposes four or five ways to solve a creative problem. He asks: Were those ideas creative? The experienced man was clever, but where was the flash of genius? Upon reflection he may honestly say to himself, "If I had originated those ideas, I certainly would have thought I was being creative."

To dispel the mystery and confusion surrounding the creative process, we will present the factors that comprise successful creative engineering.

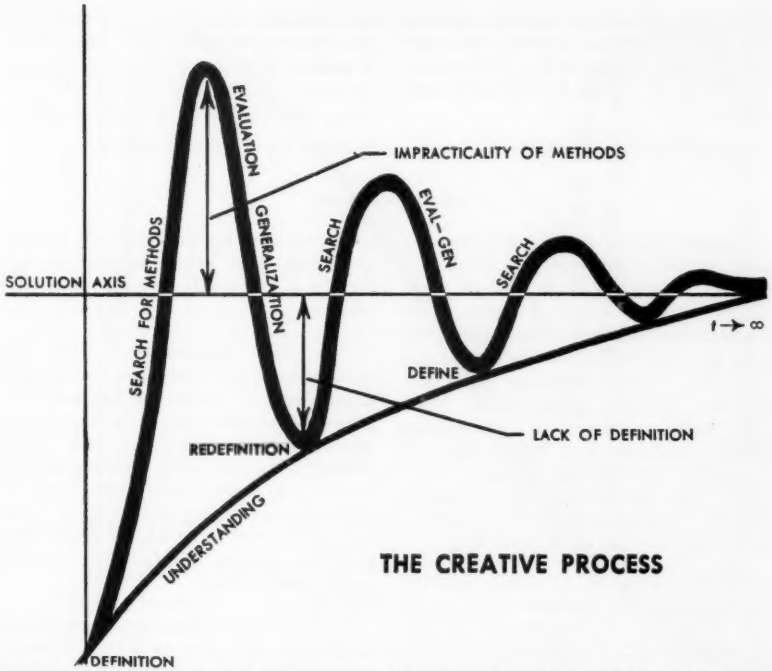

Figure 1. Creative Ability improves not only as you practice your facility for grouping knowledge into new combinations but also as you study to enlarge your capacity for understanding.

COMMON DENOMINATOR

Although the dictionary defines create "as causing to be or to come into existence," interpretations vary. For instance, when notable contributors to progress are eulogized, some people say the contributor was creative, ingenious, resourceful, brilliant, imaginative, original, an artful contriver, clever, or all of these. Others may label him imitative, fanciful, lucky, farfetched, a good guesser, a daydreamer, or unconventional. The various shades of meaning in these words, although useful in semantics, offer little understanding of the creative process. But before an understanding can be obtained, we must achieve a common but specific definition.

Creativity is not limited to any one group of people, being applicable to those in research or development, design or product engineering, the arts or sciences, and other areas. To achieve something new or different, a person must discover a new combination or application previously unknown to him. This combination might include an existing device, mechanism, linkage, fundamental law, effect, or change in attribute such as size, shape, or color.

For example, the first automobile was a buggy modified by an electric motor. Because a horse no longer turned the front wheels, a shaft and handles were extended upward, per-

mitting the driver to steer the vehicle. Still another whole industry emerged with the application of the electric motor and heater strip to the home-appliance field.

Creativity, then, is the obtaining of a combination of things or attributes that are new to the creator. Thus, when a person does something for the first time by himself, without specific previous knowledge of the technique or process, he is being creative.

WHO IS CREATIVE?

Pioneers with a minimum of equipment settled in undeveloped areas and created a successful livelihood from the natural materials at hand. More recently the Seabees earned immortal fame by their ability to build airstrips and other war needs under great adversity. Theater productions have often been presented on a shoestring budget. And in spite of inadequate equipment, the answers to many laboratory experiments are still achieved. Creativity in all these areas is synonymous with the art of improvising.

Another area of creative activity comes under the general heading of rationalization. An individual may be so engaged when justifying his job, asking for a raise, devising methods of coping with unexpected trouble, worrying about an imaginary evil, and building dream castles in the air. A person who lives in a housing development, where every house on the block is the same, exercises a rather simple creative process by giving an individual appearance to his home. To achieve this difference, he can select from a wide variety of color combinations, choose various types of landscaping, or add a porch, storm shutters, or a decorative fence. By presenting a variety of menus and table settings to her family, a housewife also displays creativity.

A student, apprentice, or any beginner must be creative to accomplish a problem or task that he has not been specifically instructed in. For example, problems at the end of a chapter of any mathematics textbook usually do not reveal the steps to solution. Only by carefully searching the chapter contents and combining bits of knowledge can the student finally arrive at the right combination.

Small children illustrate outstanding examples of creativity in the form of imagination and curiosity. To a child, a stick is his trusty rifle or his prancing stallion; a mound of sand is an impenetrable fortress or, a moment later, a towering cliff to tunnel. And his curiosity is just as active. Everything he sees merits an inquisitive tug or close inspection.

We may conclude, then, that everyone can be creative through the use of imagination, logic, chance, mechanical methods, or in other ways.

WHAT STIFLES CREATIVITY?

With creativity not confined to a select few, let's look at the reasons why useful creativity is not universally utilized.

Although naturally creative, a child lacks judgment (Fig. 2). As a result, most of his creative expressions are suppressed with choruses of "don't," "no," "stop that," and "just wait until I get you home." Similarly, from grammar school through college, emphasis is placed on subjugation to fixed and well-explained text assignments, closely directed laboratory experi-

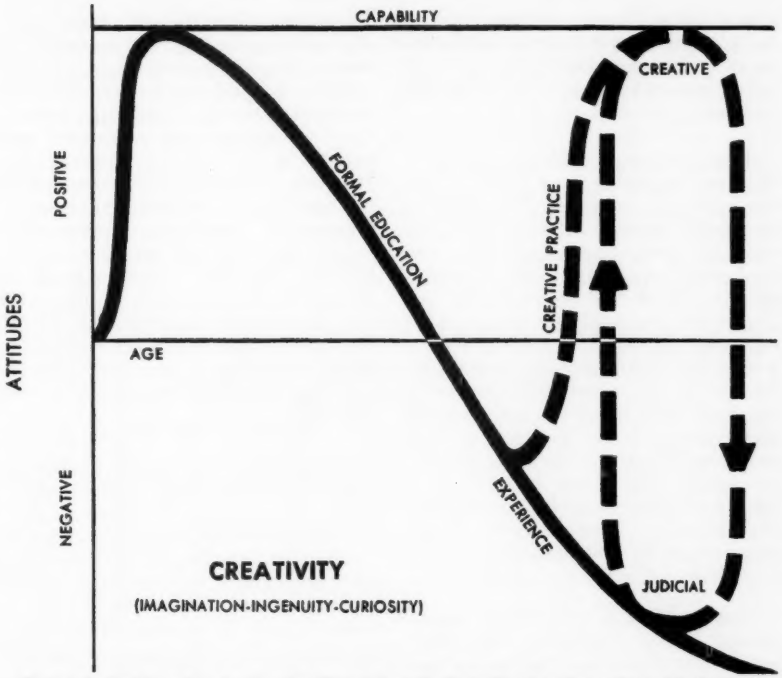

Figure 2. Subjugation to closely directed well-disciplined activity from kindergarten through the college years tends to encourage conformity and smother creative expression and curiosity.

ments, and well-disciplined study periods. Now, this in itself isn't bad except that it provides little outlet for creative expression. Consequently, creativity and curiosity dwindle and lie dormant through sheer lack of exercise.

Other factors also contribute to submerging creative expression. If a child's physical characteristics or clothing differ from his associates, he is often a subject of laughter and derision. With such bitter object lessons in conformity, it is no wonder that a child's creativity is stifled. A twofold damaging effect results: a feeling that they lack opportunity to apply creativity to solve their problems and the desire to actually resist change.

College training also has adverse effects on creativity. For example, the assignments given in a typical engineering institution could be likened to a footbridge across a wide, deep chasm. The bridge represents the problem with the solution at the other end. Such factors as the detailed definition, boundary conditions, and applicable formulas or procedures given in the text form strong and sturdy guide rails.

As the student progresses, he crosses longer bridges with little difficulty because each is still protected by guard rails. Then comes graduation with a sheepskin instead of guard rails. Small wonder that new engineers are hesitant and indecisive about what to do and

how to begin. They have learned to use the safely guarded bridges and refuse to cross a creative bridge when they see it, simply because it has no guard rails to lead and guide them.

After working problems that have only one approach, one method, and one answer, with all the working knowledge in the written material immediately preceding the problem, you can easily see why most engineers readily accept the conventional approach. Any automobile design is all right as long as it keeps the horsepower up front like grandpa's buggy. It must have four wheels, hinged doors, and roll-down windows—like the old stagecoaches—even though this may not be the most economical or practical design. The same is true with a refrigerator design, as long as it looks like an icebox. Any electric or gas range is equally satisfactory if it closely resembles the old wood stove.

Because of this educational background, many engineers and other people fail to realize that many approaches can be used to solve the problems they are responsible for. Not only that, but the methods for applying each of these approaches are numerous.

A recent article said, in effect, that the basic radio circuit has been simplified or perfected to such an extent that no further improvement is to be expected. Someone, some day, will take that as a challenge. He will look for and find a new approach, and a new radio circuit will be created.

Another example of how education can limit people's vision and their thinking is the often-heard story of the United States Patent Office Director who resigned in the late 19th century because he felt that everything had undoubtedly been invented and that his job had absolutely no future.

Another factor tends to stifle creative expression. As the standard of living progressively increases, individuals become more self-satisfied with the status quo; and self-satisfaction, or contentment with what one has, is the very enemy of creativity. The individual who first observed that the dead live in us summed the situation neatly. Too often, progress and growth are impeded because judicial thought processes depose instead of dispose a creative contribution. And so, even though industry may recognize and create a more efficient automobile, refrigerator, or range, customers will not buy if the product is too different.

But perhaps the biggest stifler of useful creativity stems from its definition. Inherently, the entire span of the creative bridge is initially untested —full of unknowns and possible dangers. Sometimes the creative process can be successful only through a fierce determination to succeed. When notable inventors finally overcome the last obstacle in their creative process, we can easily understand why their elation is so vividly recorded. The same thrill exists in any situation where a person sets himself a challenge and is victorious. But pathetically few have enjoyed this thrill. Time and time again, creative bridges can be and have been safely crossed by the strong-willed few who dared. And anyone can safely dare if he will merely practice.

For example, the apprentice carpenter or construction man first relies on overadequate railings on his scaffolds. Then as he becomes accustomed to walking and working high above the ground, he works confidently on a bare scaffold.

A similar approach should be used

in any course in college or elsewhere to develop creativity. The problems or situations first presented should be well defined, with solutions or methods readily apparent to one familiar with the creative process. As the student's confidence increases, progressively more difficult problems without obvious solution can be given until the student has the confidence necessary to tackle any creative situation that presents itself.

A strong desire to create is essential in the useful creative process. All too often in engineering, this desire has come only when competition or other factors have forced the discarding of the old blueprints or techniques.

In spite of a strong desire and competence on the part of the individual to achieve new combinations, a successful result is not assured. Understanding in the area where he wishes to create must also be present.

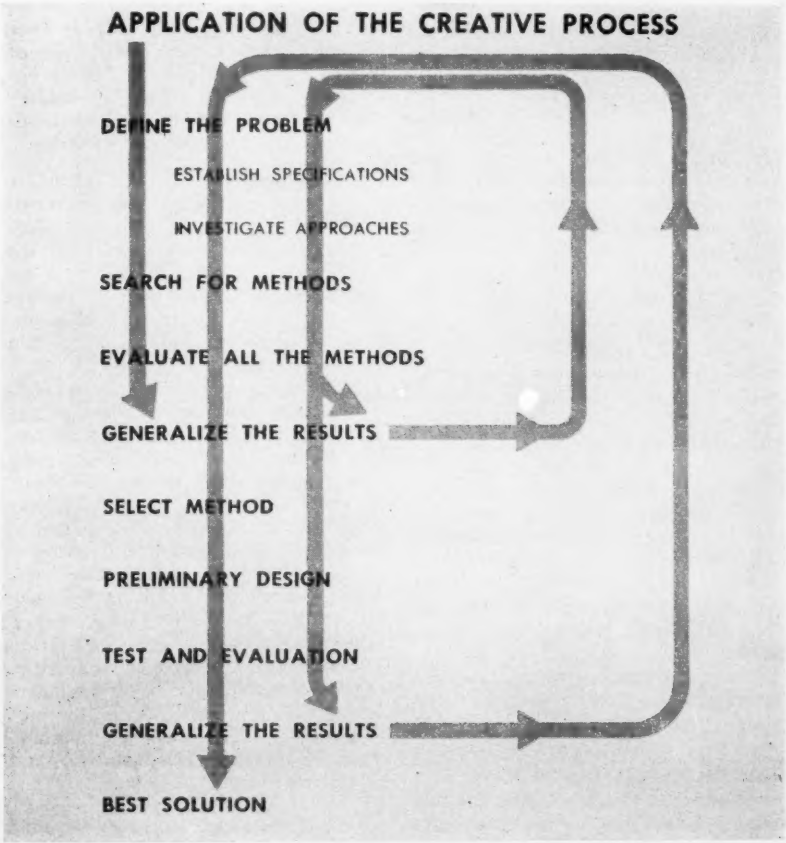

Figure 3. Creative Expression to be efficient and successful must be planned and scheduled, and recommended procedures followed either consciously or subconsciously.

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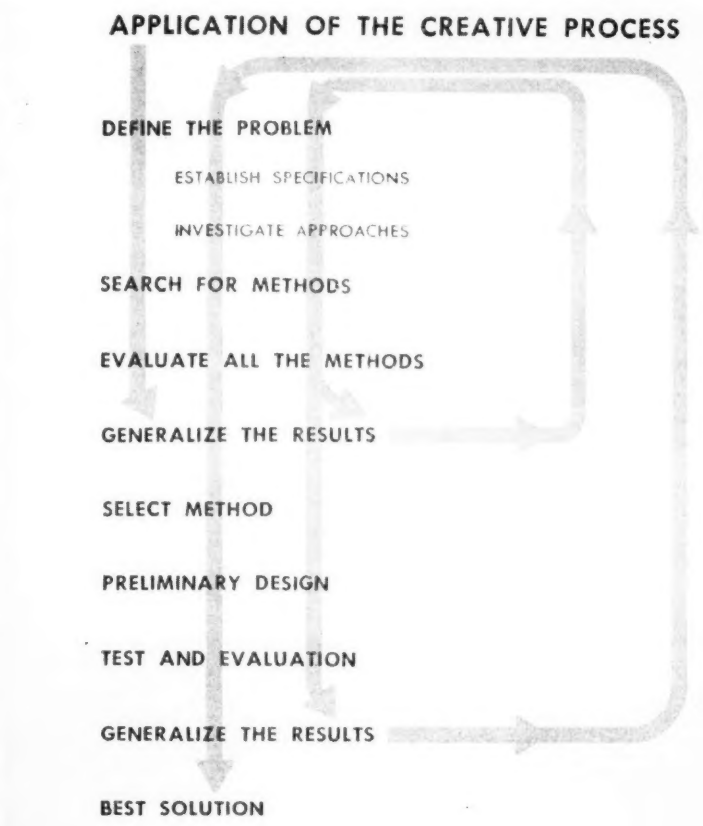


Figure 3. Creative Expression to be efficient and successful must be planned and scheduled, and recommended procedures followed either consciously or subconsciously.

HOW TO ACQUIRE UNDERSTANDING

An individual may exhibit creativity regardless of his level of understanding a problem. The usefulness, however, of the ideas generated is strictly a function of his understanding of the fundamental concepts involved. The quality of his ideas will become higher as his understanding of the problem becomes greater. Initial ideas are often discarded after additional effort is expended. And as understanding increases, the additional idea combinations that evolve will better satisfy the real needs.

Further, understanding increases with frequency of exposure to a concept or to a situation. For example, each time a new theorem is presented in a mathematics course, the student achieves understanding by successively solving more difficult and different problems, applying the theorem in their solution. His understanding increases still more when he applies this learning to other areas where the theorem would be useful.

Thus, when a situation presents itself, it should first be defined as basically as initial understanding permits. This should be followed by investigating the various approaches that could solve the problem and by searching for the specific methods to accomplish each approach (Fig. 3). Evaluating each method by asking "how could this be made to accomplish the problem definition" permits a generalization of the results, leading to a better understanding of how best to solve. To further improve understanding, the problem definition is reviewed and the entire procedure repeated.

At this point, the understanding could be called two-dimensional—a paper solution. Far from complete, this solution must first be transformed into a preliminary design—a working three-dimensional model. Testing and evaluating this model, as well as generalizing on the results, may reveal an incompleteness of understanding. And so, once again, the definition is reviewed, and the entire procedure repeated until complete three-dimensional understanding is achieved.

As in other activities, the fourth-dimensional unit — time — nearly always affects the final results attained in an engineering problem. Thus the result used best fits the problem requirements in the budgeted time, even though understanding would increase and a better solution would be obtained if more time were available—still another reason why so much opportunity for creativity exists today.

Once thought of, the best ideas are often amazingly simple; and in retrospect the embryonic solutions seem ridiculous when compared with the simple result. However, they were essential steps in achieving an understanding of how best to solve the problem. It becomes obvious, then, that people trained throughout all their educational experience in the one-problem one-solution philosophy experience difficulty in achieving this understanding. By typically accepting the first method that occurs to them, they encounter unforeseen stumbling blocks from factors they neglected to consider. And instead of attempting to evaluate their mistakes, achieve new understanding as a result, and rework the problem, they continue on, ending with a top-heavy device difficult to manufacture and even more difficult to market. This tendency of engineers allows the competitor to enter the picture, do a little more investigating, create a much better solution, and offer a more saleable product.

To find the gem, or pearl, of an idea that will give undisputed product leadership is the practical application of the creative process. How does the

pearl fisherman find his pearl? Suppose on a given day, he is told to go out in his boat, obtain one pearl, and be back at the shore within a specified time. He will be paid an amount proportional to the value of his pearl.

Now, some fishermen of narrow viewpoint will dash out, find a pearl, and race back for their commission. But the majority will realize that they stand to gain if, on the way out, they will estimate the return time, probable number of oysters, and the breaking and evaluating time. Thus they know the maximum time they can spend in the water actively searching for and accumulating oysters. By this efficient system the fishermen not only obtain a larger quantity of oysters but also are smart enough to break open all of the oysters after their search. The results can then be carefully and judiciously examined, and the largest and most perfect pearl selected, giving both the employer and the divers the greatest return on their investment of time and money.

Besides showing the value of searching for many methods and soundly evaluating all of them, this analogy shows how the planning and scheduling of creative activity is normally accomplished (Fig. 1).

Theoretically and practically, complete understanding occurs at infinite time, for the true definition places in proper perspective all the factors of quality, cost, and customer needs. Difficult to place in absolute perspective, they change with advances as new materials and processes become available to the designer and as consumers' likes and dislikes vary. Consequently, the creative process, although limited by the economics of time and money available during any given period, always affords the opportunity for achieving a better solution.

Thus to improve creative ability, one needs to expand his accumulation of knowledge and sources for reference, improve through practice his facility for grouping knowledge into new combinations, and improve through study his capability for understanding.

By following consciously or subconsciously the recommended procedures, one can successfully create; but to create efficiently on a repeatable and predictable basis, one must plan and schedule this activity.

Using the steps in the creative process has one objective—achieving problem understanding so that the best method will be obvious.

Initial problems should be relatively simple and taken from areas familiar to the student, such as the home or the automobile. To facilitate understanding, time should be scheduled for generalizing and projecting any specific knowledge into other uses and useful tools should be provided. Ideally, training should include model shop construction activity to give experience in three-dimensional understanding. The instructor should take adequate time to lead the hesitant over their first creative hurdles, but his counseling should progressively decrease.

TODAY'S OPPORTUNITIES

Man's progress continues as a function of the existing quantity of separate thoughts and things, the intercommunication between tribes or nations, and the permissive atmosphere of his environment. Look, then, at the tremendous opportunities for creative expression today! Each new idea becomes in itself an additional building block to be combined with any of the already existent blocks. Thus creativity is not degenerative; the patent office need never close because everything has been invented. Rather, creativity is a

regenerative process with each new contribution permitting a whole series of additional combinations or creations as does each discovery of a new effect or property.

Several factors stimulate the need for creative processes: Every design is a compromise achieving only the best possible solution within a given time; new effects, new materials, and manufacturing processes are continuously being discovered and developed; and, of course, customer desires are constantly changing. Thus creative opportunity exists and always will exist in every phase of engineering activity.

PART II
CREATIVITY CAN BE DEVELOPED

The notion that only a few extraordinary individuals possess creative ability still lingers in contemporary thought. Some believe that an unknown power caused such men as da Vinci, Michelangelo, Bacon, Faraday, and Edison to produce their ideas rapidly and fluently. The feeling that creativity is necessary only to inventors, researchers, and designers minimizes its importance in such fields as engineering analysis. Although creativity is subject to illusive interpretations, in the past 30 years creativity has been recognized as an asset to everyone in all fields of endeavor.

Essentially, all work requiring conscious thought consists of a continuous series of problems or unanswered questions. Men thought to be creative in the past recognized unusual problems and originally and uniquely solved them. However, anyone who solves any problem is being creative to some degree, if he is unaware of the existing solution.

The study of acknowledged creative-problem solutions revealed that all problems are solved in a logical, chronological sequence that we shall call the creative approach. We believe that everyone has a certain innate creative ability that can be developed by teaching a procedural problem approach together with useful techniques for cultivating the imagination. The problem approach not only increases a man's ability to arrive at a unique and original solution but also clarifies his thinking when faced with an unsolved problem. Regardless of where the problem lies—marketing, engineering, product development, research, manufacturing, or human relations—this approach is useful.

To present these concepts to engineers in General Electric's operating departments, the Engineering Education and Training Section developed the Creative Approach Seminar—a two-hour-per-week group discussion lasting 16 weeks. A man's creative techniques and attitudes are greatly strengthened in these sessions because of the conscious thought given to the chronological problem approach.

Our trained thought processes, begun in childhood, make us unconsciously evaluate and judge most actions that we undertake. Practically all formalized education, including physics, mathematics, and logic, teaches us to tread toward our goal on a careful path surrounded by criticism. Our inhibitions burden so many of us that we immediately reject the mere suggestion of an untried idea, letting irrevelant facts or fears blind us. Participants in the Creative Approach Seminar learn to leave the judicial and critical portions of their thinking behind and to work creatively and uninhibited toward a problem's solution. The Seminar leader allows no negative comment in the initial problem-solving stages—the sky is the limit. After some

participation in Seminar sessions, plus 8 to 15 hours of outside study every week, a marked improvement can be seen in the group's ability to get to the core of the problem. Soon the class originates and develops unique forward-looking answers to difficult problems.

The participants study many tested techniques that increase the flow of problem-solving ideas. By the end of the Seminar, a class member easily completes at least 20 ideas on a typical design problem. The group learns to use team techniques—a brainstorm session where 50 to 150 ideas can be originated in 10 to 30 minutes.

In a recent problem submitted by the Small Appliance Division, a quick method was needed to join two electric conductors together. A brainstorm session on this problem collected 175 ideas in less than 30 minutes. The class members learn how to cultivate inspiration and illumination and how to utilize these phenomena more effectively. Modification techniques show how existing solutions to related problems can be adapted or used as step-off points toward other solutions.

A PROBLEM APPROACH

An engineer's responsibility lies not only in accumulating unique ideas but also in organizing and controlling his work in an orderly and efficient manner. Many engineers tend to accept the first thought that comes to mind rather than to carefully define the problem and search for a variety of solutions. For example, a situation existed in a plant producing small, individual items, each separately packed and boxed by hand—an expensive operation. Because the situation was ideally suited to automation, an automatic machine using a novel one-piece insert was designed and built.

One packaging specification stated that the container must satisfy the customer who purchased the items. A check of the marketing organization produced a list of customers comprised of two major types: over-the-counter customers and manufacturers of motorized machinery. When polled, the first group expressed satisfaction with the new package, stating that at least it was not inferior to the old one. To the surprise of everyone, however, the machinery manufacturers were adamant against any individual package. Unpacking each item before they could install it in their product wasted time.

Checking the product distribution showed that 90 per cent of the sales were made to the manufacturers. Thus the real problem was not packaging the items individually but packaging them in bulk. The eventual solution utilized a simple pallet type of loading that eliminated the major packing cost. A more careful initial investigation and definition of this problem would have avoided considerable misdirected expense and effort.

The Creative Engineering Program has evolved a system that assists in all problem-solving situations (Fig. 4). When the Program began in 1936, two areas in every question were obvious: the problem and the solution. This developed into the four-step approach, widely publicized from 1950 to 1953. When the four-step approach was applied to the more technical type of problem, certain areas proved to be weak or lacking, and so a more refined type of approach evolved.

If the experienced engineer analyzes his own problem-solving procedure, he will find that he automatically follows the steps discussed in the Creative Approach Seminar. However, few of us carefully analyze the segments of our thinking, although to do so would greatly improve our own attack on a problem. Often we neglect or are weak in certain areas of our personal approach.

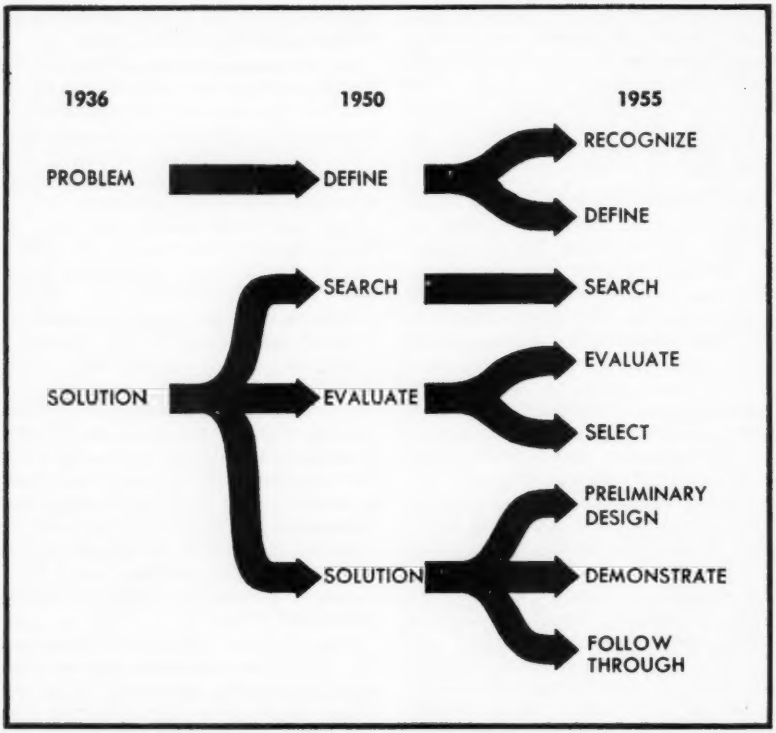


Figure 4. Evolution of problem approach concept.

A practical case history of this problem approach can be followed in the early development of an infinitely variable heat control for the General Electric range, as done by the engineers on the Creative Engineering Program.

Step 1: Recognize—Although electric range manufacturers have found that five specific heats are sufficient to perform all surface cooking operations satisfactorily, a need has been expressed for in-between heats to compensate for differences in heat transfer that result from the type, quality, and condition of cooking utensils. It is generally the feeling that the consumer will not pay a premium for this additional flexibility, and the problem, therefore, is to develop a low-cost infinite heat control for the surface units of an electric range.

Step 2: Define—The engineers considered the purpose of the device, the necessary functions, and approaches for providing an infinitely controllable supply of heat. A word definition would be: "A new low-cost control for the electric range is desired to promote the ease of cooking and sales appeal." Specifications were:

Infinitely variable control of heat
Retention of console theme and control-panel design

Easily cleaned control panel
Long life
Reliability
Low cost ($1.50 per control)
No radio interference
Fast heating
No-burning feature desirable.

The investigation that followed added to the understanding of heat transfer, consumer expectation of a range, required heat magnitudes, and the like.

Step 3: Search for Methods—To find a method that would meet the specifications arrived at in Step 2, the engineers applied creative techniques for making a number of possible suggestions to solve their problems. Of the 65 ideas suggested in the report, a few of the categories and some of their resulting ideas follow:

1. Mechanical On-Off heat controls
   - Common cycling methods
     - Motor driven
     - Solenoid driven
   - Constant- or variable-frequency oscillators
     - Thermal bellows
     - Time-delay relays
     - Electrostatic clutch
     - Thermistors
     - Bimetal oscillators
   - Vibrating or resonant devices
     - Escapement devices
     - Variable dampened resonators
2. Electrical methods of heat control
   - Potentiometer spanning small increments
   - Autotransformers
   - Variable core reactors
   - Gas-tube saw-tooth generators
   - Rectifiers
   - Induction heating
3. Other methods of heat control
   - Vary losses from heating unit
   - Vary mass of heating unit
4. Types of actuation
   - Turn a dial
   - Move a slider
   - Press kinky tube
   - Press hydraulic tube

Step 4: Evaluate—A long list of thoughts and ideas has little value unless it can be turned into a useful concept for a final product. Thus a constructive evaluation of the ideas was made. Analytical and empirical methods were used in determining the feasibility of operation of the suggested ideas, and much creative thought was needed to properly combine and integrate the good ideas into worthwhile proposals. Seldom of value by itself, one idea must combine with many to make one composite practical suggestion. In this problem, the engineers, through a series of combinations and recombinations, arrived at six theoretically practical proposals.

Step 5: Select—The selection of the basic idea to be developed later was made by comparing the six proposals of Step 4 with each other, thereby establishing a reference for judgment. The selected idea—a bimetal reed that alternately applied and removed electric power to the heating element—resulted from combining three of the ideas in the Search-for-Methods phase. The reed completed the power circuit at both ends of its oscillation, the total power being varied by changing the reed's length of travel, thereby varying the proportion of on time to off time. The resultant control was infinitely variable and independent of line voltage and ambient temperature.

Step 6: Preliminary Design—A prototype was constructed, tested, and redesigned to provide low cost and ease of manufacture. From a sketch of a manufacturing floor plan, the cost appeared to be 38¢ on an annual production of 25,000 units—considerably less than the goal of $1.50.

Step 7: Demonstrate—After seeing results and model, engineers in the range development section of the Company's Range and Water Heater Department, Major Appliance Division,

Appliance Park, Louisville, Ky., were immediately attracted by the low-cost solution to this old problem achieved through application of the creative approach.

Step 8: Follow Through—Additional work by the engineers at the Range and Water Heater Department has demonstrated the feasibility of the solution that is currently undergoing refinement.

Although this example was a relatively long development problem, the Problem Approach can be applied equally well to short problems in every field—from mathematics to appearance design. For its application to another typical problem, see the appendix. All the steps of an over-all approach to a lengthy problem constitute a succession of smaller problems—also solved by the problem approach. Thus the Creative Approach Seminar demonstrates creative techniques and how to plan and organize your thoughts and actions—a guide through uncertainty and indecision. By following an organized approach in any problem, an engineer not only eliminates wasted time spent in disorganized thoughts but also plans and schedules time efficiently. Steps of the problem approach serve as concrete chronological objectives.

CONTENT OF SEMINAR

The Seminar's simple and direct objective—to increase the problem-solving ability of the engineer in his everyday work—can be accomplished by homework and class participation.

Homework Assignments—Of utmost importance, the homework design problems give the engineer the opportunity of attacking current problems with class techniques and serve as fuel for class discussions. The source of the problem may be any one of the Company's operating departments.

One problem used in the Seminar is the design of a constant temperature device for use in a process-control instrument that must meet rigid temperature-control specifications. Another problem is to originate a new means of deactivating the start windings of a single-phase motor to replace the presently effective but cumbersome and difficult-to-adjust centrifugal switch mechanism. The solutions presented by class members are often incorporated in a product. The interchange of problems from department to department provides a fresh outlook and long-range improvements.

In addition to the design problem, each class member weekly submits an idea for creating a new product or for solving a current problem. In this way the engineer gains experience in recognizing areas of possible improvement in the respective departments and in providing new outlets for development and expansion. Further, it stimulates the student and encourages an open-minded alert attitude. At the end of the Seminar, the ideas are published and distributed to interested departments, thus providing recognition to the participants, as well as a source of new ideas for the Company. The results indicate that this system has noticeably increased the individual's awareness and his desire to improve his department and product, at the same time strengthening his ability to recognize new needs.

Class discussions on assigned literature are valuable. The texts used for the Seminar come from many sources. Some articles are supplied by Company authors or by experienced engineers outside the Company.

Class Discussions—These two-hour weekly sessions draw out every participant. Often the class leader briefly introduces the subject, or an expert in a particular field begins the meeting

with a lecture. The class leader then guides the participants toward a more effective problem-solving technique. This active participation challenges each man to think of his own shortcomings, clearly pointing the way toward developing his latent talents. Such topics as specific development methods, value analysis, design and idea problems, creative techniques, and idea stimulators are discussed, forming the backbone of the Seminar topics.

By promoting an atmosphere of openmindedness, accomplishment, and confidence in one's own creative ability, the Seminar introduces a new concept in engineering work and its co-ordination. The problem approach fosters the ability to plan for the unknown and to meet schedules. Using these principles to manage an engineering organization raises level of performance, resulting in better design quality, new products, and improved existing products.

The broad concepts and understanding gained by the engineers reduces irritation by simplifying liaison problems between manufacturing and engineering and by assisting the engineer in adapting himself to the problems of his associates. Probably most important, the Seminar encourages each class member to originate constructive forward-looking ideas that result in increased satisfaction and greater contribution to his work. The Creative Approach Seminar both enlivens and adds impetus to any department.

APPENDIX

Typical Problem Solution Using A Creative Approach

STEP 1—RECOGNIZE

Because thrust in a jet engine is a function of mass fuel flow, the Air Force needed a device to measure the mass rate of flow to the engine. At that time the meters used were unsuitable, because compensation had to be made for errors caused by density and viscosity changes of the fluids.

STEP 2—DEFINE

General Electric and the Air Force jointly prepared such specifications as . . .

Flow measurement on a mass basis independent of fluid density and viscosity
Low pressure loss
Small size and weight
Linear response
High accuracy
No temperature error
No vibration error
Long life (2000 hours minimum)
Pass salt-spray test
Be independent of fuel used.

STEP 3— SEARCH

A few of the numerous ideas considered included . . .

Coriolis principle
Variable area nozzle
Flettner principle
Restrained propeller
Rotating propeller
Angular change of momentum.

STEP 4—EVALUATE

The practical and theoretical soundness of these principles was carefully investigated. Mathematical derivations helped to calculate required size, pressure loss, and relationships of output signal. A sample based on the Coriolis principle proved practical, although rather large.

STEP 5—SELECT

The ideas developed to the point of practicality in Step 4 were compared with each other to decide on the one most nearly meeting the specifications. The small-sized angular momentum change device appeared most promising and was selected for its low pressure drop and its promise to give a linear output with input mass rate of flow.

STEP 6—PRELIMINARY DESIGN

A carefully constructed prototype sample based on mathematical calculations arrived at in Step 4 was tested, modified slightly, and retested. It completely fulfilled the rigid Air Force specifications.

STEP 7—DEMONSTRATE

The prototype sample, proved to the engineers' satisfaction, was demonstrated to the Air Force and accepted for production design and manufacture.

STEP 8—FOLLOW THROUGH

Although the engineers had completed their job of fundamental theory and design, they followed the design through its manufacturing and production stages —probably a never-ending phase.

GROUP DECISION

C. W. SHILLING, M.D.

THE AUTHOR

is Deputy Director of the Division of Biology and Medicine of the U.S. Atomic Energy Commission, having recently retired from the Medical Corps of the U.S. Navy after twenty-eight years of service.

During his time in the Navy, he spent fifteen years in research administration, nine of which was as Director of Naval Medical Research Laboratory in New London, Conn., and six of which was with the Office of Naval Research in Washington, assisting in the direction of a national research program. As a research administrator, he was naturally interested in the problems of committees and conferences. The material for this paper was derived from his personal experiences as well as from a study of available published material.

In any nation whose form of government is "of the people, by the people, for the people" it is axiomatic that most, if not all, decisions are the result of group consideration. In both the executive and legislative branches of our government all major decisions are arrived at in this manner. This means that several people, a *committee*, have met in a *conference* and, after considering all aspects of the problem, have reached a decision.

The importance of the group-decision method is evidenced by the enormous number of man-hours spent "in conference" in Washington. It is impossible to even estimate the time spent thus by the several federal agencies, but we can get a reasonably good approximation of the military use of the group-decision method by studying the Department of Defense Directory of Boards and Committees put out by the Administrative Office of the Office of the Secretary of Defense. Here we find permanent groups ranging alphabetically from "Abrasives and polishing materials technical committee" to "Wrought iron and wrought steel pipe and tubing"; in importance from international to minute detail, "Brazil-U. S. defense commission, joint" to "Brick and building tile technical committee"; and from the sublime to the seemingly ridiculous, "Defense board, inter-American" to "Outline of form committee." A further insight into the diverse coverage may be glimpsed by noting that listed alphabetically under the letter "P," for example, are 108 permanently established boards or committees covering such subjects as: packaging, packing, paint, paper, parole, parts, Passamaquoddy, patents, pathology, payroll, per diem, personnel, pest, petroleum, pharmacology, photography, photolithography, physiology, pipe, plans, plastics, etc., etc. In fact, in one year's "Directory" there were 1803 officially sanctioned permanent boards and committees.

Now add to this list all of the thousands of smaller unofficial group meetings held within the structure of every

unit in every division of every bureau of each military department, and consider the fact that many such groups meet at least each week, and it is evident that the total number of man-hours thus spent each year is indeed staggering. In addition, there are many man-hours spent by other groups and agencies working for the military. For example, the National Academy of Sciences-National Research Council estimates that in a given year between 68,000 and 80,000 man-hours are devoted to meetings and conferences for the Department of Defense and the Atomic Energy Commission.

However, lest we think that the Federal government, and in particular the military, is the only group relying upon committee or group decisions, one has but to look around in any community to find that committees are the cornerstone of all administrative activity at all levels. They are indispensable to political parties, women's groups, community activities, schools, parent-teacher groups, college faculties, alumni associations, churches, lodges, civic groups, unions, industrial associations; in fact, in practically every phase of our social and community life.

It is obvious that committee membership and activity will be experienced by everyone from the cradle to the grave—at least from kindergarten to the old people's home. This means, or should mean, that everyone ought to know something about this democratic way of reaching decisions. This is particularly true of those in an administrative capacity in the Federal government whose job requires the ability to run a conference or direct the activity of a committee.

But what is known scientifically about this obviously important facet of our national life? What are the qualities of leadership required of a good chairman? What do we know about the proper composition of a committee? Do we know what is necessary in order to insure that a conference will be a success? How can we get the maximum value with a minimum of man-hours spent? In order to obtain scientifically accurate answers to these and many other pertinent questions concerning the group-decision method the Office of Naval Research supported studies under contract with the University of Michigan. Much of the material in this article is based on the results of this investigation.

First, what is a committee? There are a number of ways of defining a committee. Two facetious definitions are: "A committee is a group of people who individually can do nothing but collectively can decide that nothing can be done," and "A group of the unfit, appointed by the unwilling, to do the unnecessary." Webster, in a more serious mood, says a committee is "A body of persons appointed or elected to consider, investigate, or take action upon, and usually to report concerning some matter or business, as by a court, legislative body or a number of persons." By an analysis of their action it is possible to identify several types of committees functioning in our governmental structure: the informative, the advisory, the symposium type for group exchange of ideas, the administrative, the problem-solving, the decision-making, the legislative, and the judiciary.

What is a conference? From personal experience, a secretary's report that "He is in conference now and cannot be disturbed" may mean almost anything. Webster's definition of a conference is "A meeting for consultation, discussion, or an interchange of opinions, whether of individuals or groups." But for the purpose of this discussion, a conference will be considered to be a meeting of some type of committee.

One of the first considerations in conference management in the minds of most people is controlling the physical environment. The following factors are often considered important: the room should be properly lighted; the temperature should be just right—definitely not warm enough to put everyone to sleep; the ambient decibel level should be kept low and participants should speak distinctly; chairs should be comfortable, but not too comfortable; the table should be of such a shape that the maximum number of conferees can see each other; a pad of paper and a pencil for doodling purposes should be at each place; and ash trays of ample size should be provided for those who wish to enhance their chances of lung cancer.

But let me hasten to say that many of the greatest decisions have been made by groups meeting in much less ideal surroundings: in tents under gunfire; in a dank dark dungeon; aboard ship during the noise of battle; under threat of imminent death from a howling mob; and under pressure from many other types of distraction. And yet these conferences were completely successful both in the satisfaction experienced by the participants and in the final outcome resulting from their decisions

This does not mean that no care should be exercised in planning the environmental setting for a conference; but a pleasant and well-regulated enviroment does not insure a successful conference by any means, for there are other much more fundamental requirements.

The composition of a committee is important because every human being brings to any situation his entire background of training, experience, religious beliefs, emotional reactions, and physical condition; and all of his decisions are colored by this complex of personal make-up. This leads, as the psychologists say, to participants speaking about a given problem at "different levels of conceptualization," or "in different frames of reference." Thus, when selecting an individual for work on a particular committee it is vital to know as much as possible about his background and therefore what he is likely to be able to contribute to the group decision.

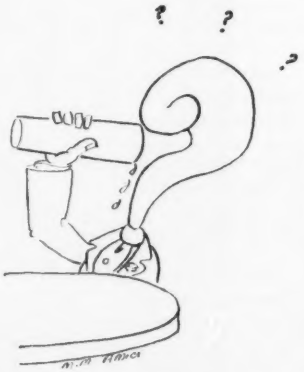
It is, of course, obvious that an individual would not be selected to function on a committee dealing with fuels and lubricants if he is a geneticist. This is to say, people should first of all be chosen for their technical competence. But in selecting the membership for any committee it is not necessary to have only the oldest and most accepted authorities in a given field. As a matter of fact, age in itself is certainly not a satisfactory criterion for committee membership. This was ably, albeit humorously, pointed out by Dr. R. Keith Cannan, Chairman, Division of Medical Science, National Research Council, in a paper read before the Medical Library Association: "In my youth I held a great reverence for committees. With advancing years I have been drawn more and more into their orbit and, to my disillusionment, I have found them composed of tired, puzzled, old fools, like myself. It would seem to be a rule of democracy that it is not until you have reached the age at which you are no longer able to manage your own affaris that you are considered to be qualified to manage the affairs of others."

Even after selecting the members with reference to their special competence in the field of interest of the committee, there are still important considerations relating to personality. There are some people whose conduct

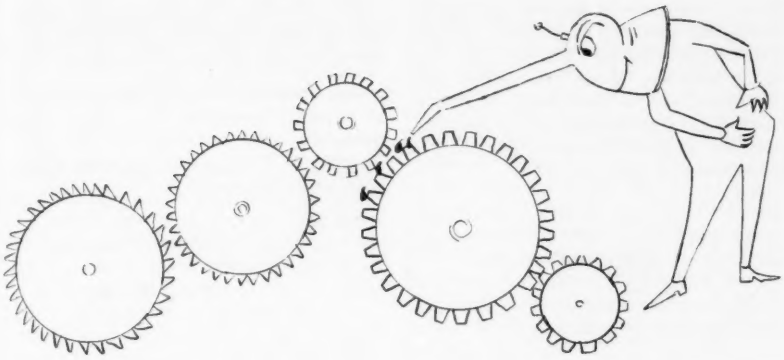
is such that you find yourself staring at them and wondering if they have not just recently been lured down from the treetop with a ripe banana. Although personality quirks cannot always be accurately recognized or defined, the different personality types sometimes found in committees are characterized in a Bureau of Naval Personnel manual entitled CONFERENCE SENSE (NavPers 91139). We have adapted their characterizations and present them by both illustration and description. The following are some of the helpful and therefore more desirable types:

The Orienter. Really acts as a navigator who becomes restless if the conference gets so murky he is unable to take a sight now and then. He keeps the position of the group fixed in relation to the problem under discussion.

The Initiator. Is a close relative of The Orienter for he keeps hammering away at the problem, and in addition he brings up new ideas and different approaches. Because of his initiative he may keep others out of the discussion, but in general is an excellent man to have on a committee.



The Information Seeker. Has an insatiable thirst for knowledge; asks a great many questions, and in his search for the facts of the case serves to help educate the entire group.



The Expediter. Guarantees smooth functioning of the group because he facilitates the participation of the various members. "I would like to hear what Mr. Y thinks."

The Encourager. Praises or agrees with and accepts contributions of others. As pointed out in CONFERENCE SENSE, "A rare and wonderful guy. Keep out of drafts. Button up his overcoat. Buy him a medical snort now and then."

The Compromiser. Disciplines himself in order to maintain group harmony by coming halfway, discarding part of his ideas and accepting part of the ideas of the other members.

The Energizer. Is always interested in pushing the discussion along as fast as possible and making certain that the group is coming up with high quality answers.

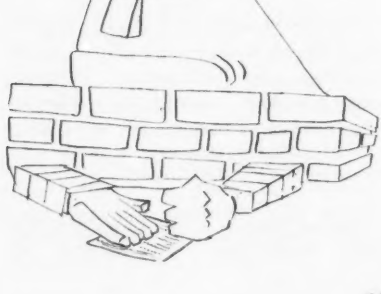
The Harmonizer. Is a man to appreciate for he makes sweet music as he mediates the differences between other members, relieves the tension in complicated situations by smoothing ruffled feathers, and does a great deal to encourage group action.

Not all members of committees are good characters. Unfortunately for

smooth progress, there are a number of undesirable types which it is our duty to call attention to. Any resemblance between these characters and persons of your acquaintance is purely coincidental. However, if you recognize yourself in any of the descriptions, it is time to mend your ways!

The Aggressor. Is a very difficult man for he tries to embarrass other members, expressing disapproval of their acts, or the value of their contributions. He is an aggressive joker; tries to take credit for another's contribution. A difficult guy.

The Closed Mind. He has personally "made up" his mind on the issue at hand and will definitely not listen to reason, no matter how logical or convincing.

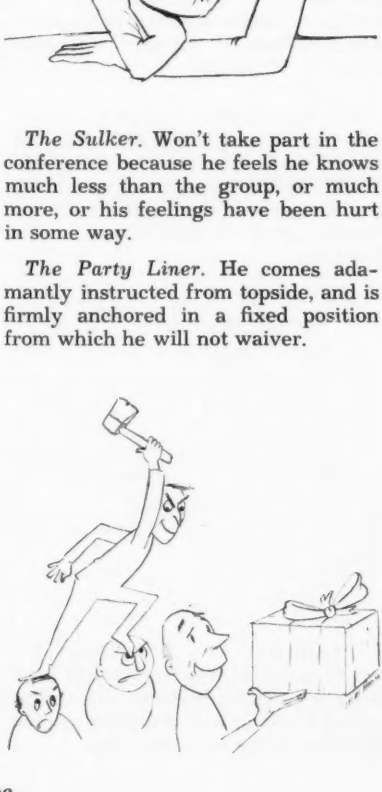


The Blocker. Opposes action; disagrees with decisions; antisocial; refuses to cooperate or compromise.

The Special Interest Pleader. Usually is actually speaking for himself but pretends to be interested in "the junior officers," "the pilots," or some other group not represented.

The Sulker. Won't take part in the conference because he feels he knows much less than the group, or much more, or his feelings have been hurt in some way.

The Party Liner. He comes adamantly instructed from topside, and is firmly anchored in a fixed position from which he will not waiver.



The Wrecker. The solution to the problem has been agreed upon; it's all tied up and ready for delivery. Then he jumps up and cuts it wide open again—"But . . ."

For effective presentation we have been exaggerating, and in some cases cartooning, personality types. The psychologists in a more scientific frame of reference identify personality and conduct of individuals in terms of "inferiority complex," "superiority complex," "ego needs," "neurotic traits," "dependency need," "aggressive behavior," "status needs," "dominance needs," and "need for catharsis." It is obvious that in all of these different types there is likely to be a deep-seated personality trait which is expressing itself in a corresponding type of behavior.

The ideal group would be one composed entirely of members who are "task oriented;" i.e., those interested solely in the expeditious solution of the problem at hand. But unfortunately such perfect groups are rare, for it is indeed difficult for anyone to divorce himself completely from the influence of the ever present personal needs. And these personal needs are often a strong motivating force for they are derived from the more basic need to "defend and enhance the organism;" i.e., the struggle for the preservation of life itself. The behavior of such individuals may be said to be "ego-oriented" or, as expressed in less scientific terms, self-centered or selfish.

However, by whatever name such behavior is called and from whatever cause it springs, those individuals having the less desirable behavioral characteristics should be excluded if possible from serving on committees. But there may be situations when the aggressor, for example, would be an ideal man to have on a committee, and opposite types can be chosen so that they will balance one another. Deviants from the accepted norm can often perform unique and valuable functions and may serve to direct the energies of the others toward the group goal. The group should be organized so that the unique abilities of the members can be utilized to the maximum. For example, one might make a good secretary or treasurer, while another could be the head of a subcommittee assigned to a specific task.

Although our illustrations include the undesirable as well as the desirable types of individuals which might make up a committee, it should be clearly understood that the undesirable types are not too often encountered in actual experience, and when encountered usually do not demonstrate the undesirable characteristic to any marked degree. Again, individuals are rarely constant in their moods or reactions for so much depends on their personal feeling at the time. Also, their conduct depends upon their knowledge of, or interest in, the subject matter before the conference.

The average individual is primarily interested in getting a job done and there are enough of the initiators, orientors, energizers, harmonizers, and so forth to counterbalance or handle any of the blockers, sulkers, special interest pleaders, or party liners of a commmittee. A capable chairman can frequently direct the energies of the different types so as to achieve the desired goal, and he can even change the sulker into a cooperative member of the group.

In addition to the individual types, in large groups it is possible that various "status levels" may exist. That is, individuals of a class—social, edu-

cational, or financial—when acting as members of a group, may tend to perpetuate their class status. This may lead to the formation of "cliques" which are really subgroups of persons who support each other and are likely to oppose those outside the clique in any conflict of interests.

We mentioned a capable chairman or conference leader. But what combination of attributes constitutes such a leader? First, the functioning of the chairman depends somewhat upon the type of conference or committee. It may be a straight informative conference called by the head of a division for the sole purpose of giving information to his subordinates. In this instance the success of the meeting depends entirely upon the chairman's leadership ability and his knowledge of the material he wishes to present. In another situation the chairman may be someone who is designated to keep order, his only function being to recognize those who wish to speak, and to monitor the meeting in accordance with Roberts' "Rules of Order." This latter type of chairman has very little opportunity to make his knowledge or leadership ability felt for he is a silent chairman, often even with no vote in final decisions. However, in most problem-solving committees, the chairman is chosen for his expertness in the subject matter of the conference. In this case he is the leader by virtue of his recognized scientific position.

Before considering how a chairman can influence the action of the committee it might be well to think of the chairman as a leader. One point of view is that leaders are born and not made, and all that one has to do is to set down a list of attributes for leadership, then find a man who has these qualities. Unfortunately for this point of view, lists of attributes have been compiled by a number of experts, no two of whom agree as to what constitutes the necessary capabilities for leadership.

Another concept is that a leader cannot be designated ahead of time for any and all occasions but must be selected for the special occasion at hand. This idea of leadership places importance on what the individuad does in the situation, not on any general characteristics which he may possess.

From the standpoint of selecting a chairman of a conference, the latter interpretation seems to be the more plausible one since, for example, an expert in psychology would obviously be lost in a conference dealing with structural steel. This is simply another way of saying that the chairman of a conference should be selected for the contribution which he is capable of making.

Regardless of his professional competence, one thing is certain—a man does not make a good leader unless he sincerely wishes to act in this capacity and unless he is willing to make the sacrifices necessary to do a creditable job. Motivation is important.

None of the above is to be construed as indicating that there are not ways of conducting a meeting by which a chairman can insure its ultimate success. For the chairman is in a position of power, particularly if he comes to the meeting prepared with all of the background information concerning the problem at hand, and with an agenda designed to accomplish the desired action. He then can skillfully lead group decision into line with his own plan of attack. This type of leadership

led me to say at one time that the conference was the democratic way of being completely autocratic. That is, the leader artfully imposes his will upon the group in such a way that each man feels he has made the decision. He can avoid criticism for this type of conduct if he does not take personal credit for everything, as has obviously been done by the little flag-waver in the figure below who has sucked the group dry and then is taking credit for the entire accomplishment. Also, the conference provides a way for such a leader to spread the responsibility and likewise the blame when things go wrong.

The actual conduct of the conference is another area of importance. Should the chairman conduct the conference in a completely informal way, as if he were a buddy of the rest of the members; or should he conduct it with strict adherence to the rules of order and with a fairly firm hand in controlling the group? It was surprising to the author to find that the majority of the groups studied preferred a reasonably firm hand for they felt that more was accomplished under such guidance. This type of chairman continuously controls the efforts of the various members, calling them back to the problem at hand and apportioning the available time. There is a danger, of course, that such a leader may stifle valuable contributions which members could make. On the other hand, he can also cut down on the tremendous waste of time resulting when everybody is allowed to air his pet opinions without any curb. The proof of this lies in the fact that the controlled committee usually demonstrates superior accomplishment, and this is what really gives satisfaction.

The capable, or perhaps we should say clever, chairman can also wield his influence by calling on people who he knows believe as he does, and he can fail to recognize or limit the time given to those who would be antagonistic. This means that the chairman is quite largely responsible for the degree of communication within the group. He can also influence the final verdict by frequently summarizing and interpreting.

From the foregoing it is apparent that it is important to select a chairman who is well informed in the subject matter under discussion, who commands the respect of the members of the committee, and who will maintain a fairly taut control.

We have considered physical environment, types of committee members, and the importance of the chairman. The big question remaining concerns what is accomplished by the committee, or as the psychologist puts the question: "What is the productivity of the conference group?" In addition to the factors already covered, accomplishment also is influenced by the

type of committee, its position in relation to the organization, the power delegated to it, and the problem or goal assigned.

Before a committee can be productive it must be determined that the problem is one that is appropriate for committee action. Some problems should not be delegated to a committee. Dr. Vannevar Bush, president of Carnegie Institute in Washington, in testimony before the Subcommittee of the House Committee on Government Operations in October, 1952, stated: "The Joint Chiefs of Staff should emphatically not be in the line of command. Its chairman should not be a supreme military commander, running the forces in the field from a desk in Washington. Joint Chiefs of Staff is a staff. To place it in the line of command is to invite military command by a *committee,* than which there is nothing worse. It should as a body issue no orders whatever, in peace or in war." We agree with Dr. Bush that action can best be taken by the man in charge at the scene of activity and not by a group back in a conference room.

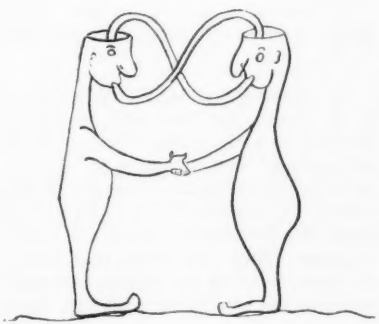
In a similar vein Dr. Mees, Director of Research of Eastman Kodak Company, said in regard to research administration: "The best person to decide what research is to be done is the person who is doing the research. The next best is the head of the department. After that you leave the field of best persons and meet increasingly worse groups. The first of these is the research director who is probably wrong more than half of the time. Then comes a *committee,* which is wrong most of the time. Finally, there is the *committee* of company Vice Presidents, which is wrong all of the time." (Italics by the author.)

But let us assume that the reason for requesting committee action is valid and consider some of the types of committees and the factors affecting accomplishment. The committee meeting may have been called simply for the purpose of informing members concerning a given topic. Here accomplishment depends upon the nature of the material and the manner in which it is presented. Among the factors to be considered, the following are important: what is the level of difficultness—can the slowest of the group understand clearly and yet the presentation not offend the sharpest? How well is the presentation organized—are the points well thought out and presented in an orderly manner? Are objections anticipated and answered in the presentation? Is the need for the prescribed course of action well established? What is the tone of the presentation—is it purely informational, or is it suggested action or an order? These and many other questions must be carefully considered when preparing for an informative meeting.

The informative type of conference has the following characteristics: leader controlled rather than group controlled; restrictive rather than permissive; vertical (from the top down) rather than horizontal (free group discussion). In such presentations the nature of the discussion is usually concrete rather than abstract. The preconference agenda has been carefully planned by the leader and by higher echelon persons. There is no need for unanimity of understanding, although it would be desirable to have all hands accept the information handed down. There is no opportunity for exchange of ideas. There is no need for arriving

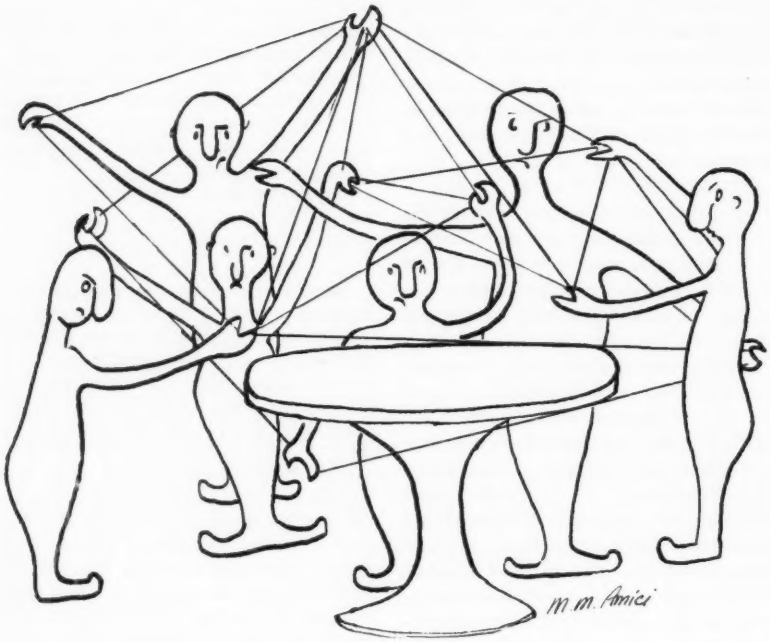
at a solution to a problem or making a group decision. The personal satisfaction derived from this type of meeting is usually very low and its success depends entirely upon the persuasive powers of the individual making the presentation.

Another type of conference is the advisory or exchange-of-ideas conference. Here, there are two goals. One is to educate the group through the exchange of ideas presented by the various members. The accompanying figure illustrates the perfect accomplishment of this goal. A secondary goal which is frequently the one most important in the minds of management is to present the problem for discussion to the group and then record or take notes on the answers in order to obtain ideas on which management will then base a decision. This type of meeting has the following general characteristics: no decision or final solution is required, therefore the conference is usually not competitive so far as the group is concerned; ideas are presented for discussion and areas requiring further information or investigation are frequently developed; it is a deliberative type of meeting; there is very little leader control for it is more group-directed; it tends to be informal rather than formal; the agenda is usually flexible and it is more horizontal than vertical in its operation. This type of conference is often used in the area of research administration in order to get a group of experts together to discuss a particular problem and to determine what is known and what areas need further elucidation.



Closely related to this type of conference is the symposium used as a method of educating large groups and for the development of information. Here a topic is assigned and experts are brought in to present formal papers dealing with its various aspects. This is then followed by a forum in which the audience or the other members of the group can present questions for discussion by the experts. For this type of conference to be a success, very careful planning must go into selecting and defining the area for discussion and in identifying the very best experts to make the presentation. It is even advisable to have questions prepared ahead of time to be asked in order to start group participation.

Another type of conference is one in which the mission is problem-solving. The group is called together and assigned a particular problem and requested to come up with a solution or answer. This requires a careful presentation of material so that the problem will be clear and the group will understand the importance of the decision to be made. This type of conference tends to have a planned agenda; is more formal than informal. Leader control must be fairly firm in order to keep the group in line for if open discussion is allowed without any control the situation may become as entangled as that depicted in the figure on the next page.



Care must be exercised to make certain that the problem is one capable of solution by the group; otherwise, complete frustration with its accompanying ulcers and coronaries will result. In this type of conference there is full play of all of the personality characteristics discussed earlier and, since a solution is required, personal and party interests may develop and cliques may be apparent; thus careful control is necessary. It is, however, important to make certain that everyone has an opportunity to present his views and that all members contribute to the final solution. In this connection I am reminded of the chairman at a meeting who announced: "In most associations half of the committee does all of the work, while the other half does nothing. I am pleased to put on record that in this society it is just the reverse." It really makes no difference which half does nothing for to achieve progress of the first order, all members must participate. Satisfaction is high in this type of conference, particularly if the members know that power has been delegated to them and that their decision will be final.

An elaborate version of this type of group action has been utilized by the military in some of their various "project groups." Here a group of top experts representing all of the disciplines which can possibly be brought to bear upon the problem at hand are called together. They are then fully indoctrinated, even to the extent of taking them to the site of the problem, dem-

onstrating everything that is known concerning it, allowing them to ask all the questions necessary, and then carrying out any research or further investigation suggested. This type of extended conference, properly handled, has been most productive.

The so-called decision-making conference is so closely related to the problem-solving type that no sharp differentiation can be made. However, in the decision-making conference the group is more apt to be part of a governing board who, after material is presented, simply decide upon a course of action. There is less likely to be a long probing discussion of an individual problem and more likely to be quick decisive action based upon information at hand. This is closely related to the administrative conference. Satisfaction obtained from this type of conference depends upon the feeling of the group relative to the importance of the decisions and the likelihood that their decisions will be carried out or put into action.

One of the most important aspects of the group-decision method is the satisfaction derived by an individual from such a meeting. Individual satisfaction depends in large measure upon a clear understanding of the problem, a feeling of its importance, and personal acceptance of the challenge. Satisfaction comes also from the realization that the proper decision has been reached and will be put into action. It is this feeling of personal involvement which accounts for the success of the clandestine meeting of a group in a cellar while a lack of personal involvement may lead to a failure of the most perfectly appointed meeting. In fact, the ultimate success of the conference, particularly in what each individual takes away with him, depends more upon the factors producing individual satisfaction than upon anything else.

THE CATHODIC PROTECTION OF SHIPS AGAINST SEA-WATER CORROSION.

ACKNOWLEDGEMENT

This article, published in the July, 1955, issue of *The Shipbuilder and Marine Engine-Builder*, is an abstract of a paper read before the Institution of Naval Architects in April, 1955. Its authors are L. T. Carter and J. T. Crennell.

The prevention of corrosion in ships is a matter of great importance to shipbuilders and shipowners. Cathodic protection is an aid to achieving it, and the purpose of this paper is to discuss the application of this process, more particularly to the under-water surface of ships' hulls.

CATHODIC PROTECTION— PRINCIPLES AND REQUIREMENTS

Definition.—

Protective coatings, at best, only delay and restrict corrosion; and in the fight against corrosion, cathodic protection provides an additional and powerful weapon. In its technique, this process differs fundamentally from the conventional methods; and, by its means, complete immunity from corrosion is not only a theoretical ideal, but is readily achieved in practice.

As normally applied, cathodic protection and protective coatings are complementary rather than competitive.

The corrosion of steel in sea-water is electro-chemical in its action; atoms of corroding iron leave the surface of the metal and go into solution as positively charged ferrous ions. This process involves the passage of current from the steel into the sea-water, and if the current can be stopped, the corrosion will also be stopped. This can be achieved by superimposing an adequate current in the opposite, or cathodic, direction. Cathodic protection, therefore, may briefly be defined as "the prevention of corrosion by the passage of a sufficient electric current through an electrolyte to the surface of the metal, in the direction which makes the metal a cathode."

In the absence of cathodic protection, some parts of the immersed steel will be anodic, delivering current into the sea-water and corroding. Since each current must pass in a closed circuit,

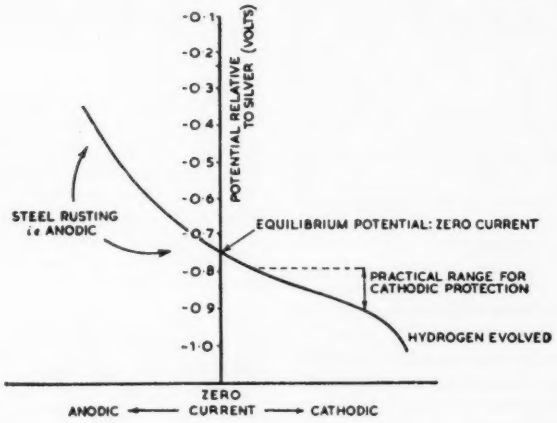


Figure 1.—Steel in Sea-water—Relation between Current and Potential.

it must return to the metal elsewhere, so that some other parts of the steel surface will be acting as cathodes and for the time being will not be corroding. To ensure that no part continues to corrode, it is necessary to apply a cathodic current sufficient to swamp all the local anodic currents. Since these cannot be measured, the quantity of protective current required cannot be accurately predicted, but there is, fortunately, a very simple means of knowing when the current for cathodic protection is adequate, *viz.*, by potential measurements.

Criterion of Cathodic Protection by Potential Measurements.

Every electro-chemical reaction has an appropriate potential, which is a measure of the energy of the reaction. The potential of hull metal in sea-water may very simply be measured against a convenient reference electrode whose potential is constant. What is measured, in effect, is the voltage of a galvanic cell, whose positive plate is the reference electrode metal, the negative plate is the metal under examination, and the electrolyte is sea-water. The reference electrode is suspended in the sea and its cable is connected to the positive terminal of a suitable voltmeter. The negative terminal of the voltmeter is connected to any convenient part of the hull where a good metallic contact can be made.

A convenient reference electrode metal for use in sea-water is silver.

The potential changes of steel in sea-water are illustrated in Fig. 1. Taking the potential of the silver electrode as the arbitrary zero, the equilibrium potential of steel in sea-water, when no current is passing, is about −0.75 volt. Steel which is rusting in sea-water commonly has a potential of about −0.6 volt, because it is acting as an anode passing current into the sea-

water. If a current from an external source is made to pass from the seawater to the steel, this will oppose the corrosion reaction, and the potential will be depressed; the fall of potential indicates the decrease in anodic current, and, hence, the increase in the degree of protection conferred. Below the equilibrium potential (−0.75 volt), the net current must be cathodic, and the steel cannot corrode; protection will then be complete.

To ensure cathodic protection, it is usual to call for a measured potential of not less than about 0.80† volt; the margin is to take care of the fact that all parts of the immersed structure will not be at the same potential and it is necessary to ensure that no local anodic areas can remain.

If the potential of the steel surface is raised above about 0.95 volt, evolution of hydrogen gas commences, slowly at first, but rising rapidly with increasing potential. For this reason, and to avoid damage to outer bottom paint by alkali formation, the cathodic current should be kept to the minimum necessary for protection. It should be the aim, therefore, in cathodic protection, to control the applied current at such a value that the potential of the protected surface, relative to silver, is held between 0.8 volt and 0.9 volt, preferably between 0.8 and 0.85 volt.

Value of Current Required for Cathodic Protection.—

The current required for cathodic protection is decided, largely, by the rate of supply of dissolved oxygen at the cathode surface, and this depends on a number of factors. One of the most important is the amount of accessible surface of steel available, which depends on the continuity and impermeability of the paint or other coating. The greater the proportion of accessible surface, the higher will be the current required.

The rate of water flow past the surface, also, has a major effect due to the greater supply of oxygen to the cathodic area; a ship requires about 50 per cent more current when at sea than when moored in a tideway, while in a non-tidal basin, the current requirement may fall as low as half the open-water value.

The current requirement is likely to decrease as time proceeds, owing to the deposition on the hull of a film of "cathodic chalk." This coating can be a considerable help in protecting the surface, and may compensate for the increased current demand due to loss of paint.

It is a common practice to apply a high current density, initially, and to let it fall away. The object of this is to raise the potential to the protected value quickly, and to lay down a calcareous coating, which will reduce the ultimate current requirement.

Methods of Application of the Cathodic Current.—

The fundamental requirements for applying cathodic protection are an anode, external to the structure to be protected (the cathode), and a source of e.m.f. to drive a current from anode to cathode. There are two distinct technics, *viz.*, one in which the anode used is a base metal, and the e.m.f. is provided by its natural difference of potential from that of the cathode; the other, in which an external source of power, such as battery, motor generator or A.C. mains using transformer and rectifier, is used.

Anode Materials.—

(a) Active (or sacrifical) anodes employed in cathodic protection are usually of magnesium alloy. The alloy,

†For convenience, the negative sign is omitted in further references to potential; only the numerical value of the potential difference from the reference electrode is quoted.

containing 6 per cent aluminum and 3 per cent zinc, is consumed at a relatively uniform rate, and supplies a reasonably constant current.

Magnesium anodes used for ships of the Reserve Fleet are cylinders 9 in. in diameter by 2 ft. 6 in. long, and weighing about 1 cwt. Excellent uniformity of corrosion is obtained on such anodes. They continue to deliver a useful current until nearly completely consumed. When new, one of these anodes delivers a current, in sea-water, of about 5 amperes.

Zinc has fallen into disrepute as an anode material owing to the inactivity of "zinc protectors." The surface becomes coated with a highly resistant crust of corrosion products which suppresses the current. Recent work has suggested that it may be possible to overcome this defect, in which case, zinc anodes would have advantages in some situations. Their particular value is that the potential of zinc is only slightly above the protected potential of the steel hull, so that they can be used with little maintenance and little danger of paint stripping.

Aluminum has been considered as an underground anode, but is not widely used in sea-water. Even more than zinc, it becomes inactive in use, due, in this case, to its protective oxide film which is normally invisible and self-repairing, and to which aluminum owes its resistance to corrosion.

(b) Inert anodes used with an impressed current may be consumable or relatively permanent. Scrap iron or steel is the most common example of a consumable anode material; it has the advantages of reasonable cost and availability, and, electro-chemically, it has ideal properties as an anode. Rather surprisingly, the anodic solution of iron, at useful current densities, is almost completely unimpeded by the accumulation of corrosion product. The rust formed is very loose and soft, and readily washes away; even if it stays in place, it has a very low electrical resistance. Current densities of up to and about 1 amp per sq. ft. can be used in open sea-water, with an anodic polarization of only about a quarter of a volt. Iron is consumed at an approximate rate of 20 lb. per ampere-year.

Relatively permanent anodes of graphite, usually impregnated with a resin binder, are in general use and give many years of service. Rods of 3 or 4-in. diameter and 3 to 5 ft. in length are usual. The maximum current density that can safely be used depends on the slow disintegration of the graphite by chlorine evolution. A disadvantage of graphite anodes is that a higher supply voltage is required. The actual polarized potential of a graphite anode is about 2 volts higher than that of an iron anode, and the smaller surface area will entail a higher resistance and a further increase in voltage requirement; an extra 6 volts in all is a reasonable allowance.

Because of the rather high anodic polarization, the copper conductor of a permanent anode will corrode if it becomes exposed to the sea. Care must be taken that the conductor is sealed from access of sea-water at its connection to the anode, and under-water cable connections should, if possible, be avoided.

Positioning of Anodes.—

The form or pattern of anodes has a considerable effect on the electrical resistance of the system. For a given weight of material, a number of small separated anodes gives a much lower resistance than a single compact anode. When using impressed current, a practical balance between complication and reduction of resistance results

in the general choice of single iron anodes, which should be extended in length, not compact blocks, or of a number of graphite anodes of standard commercial size, which should be spaced rather widely apart—say, by four or five times their own length. With magnesium anodes, the use of multiple small anodes is discouraged by their short life and proportionately greater loss by self-corrosion.

To achieve an even distribution of current over the protected surface, the anodes should, if practicable, be placed some distance away from the hull. With moored ships in sea-water, magnesium or steel anodes suspended 10 to 12 ft. from the hull give a good spread of current.

In active ships, it is not possible to suspend anodes at a distance from the hull. The usual practice is to fix the anodes to the bilge-keel, but insulated from it, and also to provide an insulating coating on the hull over an area extending a few feet from the anodes in all directions.

CATHODIC PROTECTION—LIMITATIONS AND SPECIAL PROBLEMS

The Effect of Cathodic Protection on Paint.—

When cathodic currents are in operation, alkalinity tends to develop at the hull behind the paint film. The conventional type of bottom paint, with an oil-based medium, is quickly damaged by sufficiently concentrated alkalis, which saponify the medium. The risk of softening or stripping of the paint film by cathodic protection must, therefore, be expected.

In actual practice, the damage to paint by cathodic protection, controlled at the correct potential, appears usually to be slight, provided special precautions are taken at regions of high current density.

If the application of cathodic protection to ships becomes more general, there will most probably be an increasing demand for both anti-corrosive and anti-fouling paints, which are more alkali-resistant than the conventional oil-based systems.

Effect of Rust and Scale.—

In order to ensure good paint bonding, the complete removal of rust scale (or millscale from new steel) is vitally important, whether the hull is to be cathodically protected or not. Experience shows that a paint coat on metal carrying a rust scale is much more apt to be removed by cathodic protection than a similar paint coat on clean steel. The first stage in the electrolytic removal of rust scale is probably the reduction of hard, adherent, magnetic oxide to a film of soft ferrous-oxide or hydroxide. The formation of this film between the metal and the main thickness of the scale destroys its adhesion and allows it to be detached.

The loss of overlying paint when scale detaches is obviously undesirable, but even this has some compensation when the ship is under cathodic protection. Areas descaled by cathodic protection, repainted at the next docking, and subsequently cathodically protected, will not again require descaling, but will present a perfectly prepared surface for further painting.

Effect on Fouling.—

Cathodic protection unfortunately appears to have no discouraging action on marine fouling.

A doubt has been felt, on theoretical grounds, whether cathodic protection may actually reduce the efficacy of normal anti-fouling paints, in which the toxic material is commonly copper in the form of cuprous oxide. The toxic material leaches out in sea-water, and maintains a lethal or highly injurious

concentration of copper or other poison in the shallow layer of water from which the organism feeds. It might be expected that passing an electric current from the sea-water to the hull would tend to deposit copper from this toxic layer on to the steel, thus stifling the anti-fouling action; moreover, the deposition of metallic copper might stimulate corrosion if cathodic protection were interrupted.

Experience in ships has so far shown that, with the current densities normally employed, there is no noticeable effect, positive or negative, on marine fouling.

Paint Supplementing Cathodic Protection.—

It may be asked whether it is economically justifiable to paint a structure that will be cathodically protected. In active ships, at least, there is usually no option. The ship must carry an anti-fouling paint. Moreover, it is generally agreed that to apply an anti-fouling paint, with a copper or cuprous-oxide toxin, direct on to steel, may be bad for both the steel and the anti-fouling paint, so that some sort of protective composition is also desirable.

The use of cathodic protection on bare steel is uneconomical, and a judicious combination of cathodic protection and protective coating is good practice.

Careful paint protection to supplement cathodic protection is very necessary at the water-line. It is an undoubted limitation of the value of cathodic protection that it cannot prevent rusting of the water-line area, although experience shows that some reduction of water-line corrosion is achieved.

The Evolution of Hydrogen.—

The range of potential for full cathodic protection is about 0.80 to 0.85 volt negative to the standard silver electrode. At a potential of about one volt, hydrogen starts to be evolved at a steel cathode. The evolution of hydrogen should be avoided; it is wasteful of current, it can damage the paint coats, and the possibility of hydrogen embrittlement of the steel must be considered. Admiralty experiments, to test whether hydrogen evolution caused embrittlement of cathodic steel, gave negative results, even with the much higher current densities, with free evolution of hydrogen, used in electrolytic de-scaling. It cannot be claimed that these experiments have been extensive and systematic enough to prove that no risk exists, and further experiments are being arranged. At the much lower current densities used in cathodic protection, the risk, however, seems negligible.

The generation of hydrogen from magnesium anodes forms a possible explosion risk. Magnesium anodes are in use in the cargo tanks of oil-tank ships, where adequate precautions against explosive gases must normally be provided. The use of magnesium anodes in enclosed spaces in H.M. ships, however, could not normally be accepted. Zinc anodes of improved design seem to hold out the best hope for cathodic protections of such spaces.

The Use of Cathodic Protection in Fresh-water.—

Generally speaking, cathodic protection is not a practical proposition in fresh-water. The current delivered by an anode is dependent on the specific resistance of the electrolyte, which is about 25 ohm cm. in sea-water, but it may be 50 to 100 times greater in fresh-water. The use of magnesium anodes is almost ruled out by the corresponding reduction in their current output; a cylindrical anode 2½ ft. long by 9 in. in diameter, and weighing about 1 cwt., yields about 5 amperes in sea-water, but might give only 0.05 amp. in fresh-

water. The current required to prevent corrosion is about the same in fresh or salt-water, since the availability of dissolved oxygen at the cathode is similar. It would be necessary, therefore, to use an impracticable number of magnesium anodes to ensure protection.

Corrosion in fresh-water is usually more uniform, and the total amount of corrosion is also likely to be less, since the corrosion currents will be limited in quantity as well as in range by the resistant water. It has been concluded, therefore, that cathodic protection is much less necessary in fresh-water.

Cathodic Protection of Aluminum.—

It has been found in laboratory trials that aluminum alloys, even when coupled to copper, and also the Duralumin alloys, can be cathodically protected by holding them at a potential of about 0.8 volt relative to silver.

The cathodic protection of aluminum at 0.8 volt is something of an anomaly. The true equilibrium potential of aluminum in sea-water is about 1.6 volt negative to silver; but this potential is never reached, because aluminum is normally in a passive state, with a self-repairing protective oxide film. The observed potentials of aluminum alloys in sea-water are about 0.7 volt. The true natural potential can be shown by amalgamating the aluminum, which prevents the formation of the protective film. In this condition, aluminum is vigorously attacked by sea-water, with evolution of hydrogen.

The protected potential of aluminum is about the same as that required for steel, so that aluminum-alloy underwater fittings can be used on a steel hull without risk of corrosion, if cathodically protected.

The Use of Cathodic Protection against Bacterial Corrosion.—

The stimulation of corrosion of steel in anaerobic (oxygen-free) conditions by sulphate-reducing bacteria is now well-recognized. It is more prevalent in buried structures, such as pipe-lines, in certain soils. A ship, when fully waterborne, is usually immune from this type of corrosion, but when at a tidal berth, it may rest on a muddy bottom and may be exposed to bacterial corrosion.

Bacterial corrosion is essentially an electro-chemical process, in which a corroding anode and a cathode receiving the return current are necessarily involved. There is no theoretical reason, therefore, why cathode protection should not be equally effective in both cases. A superimposed cathodic current, sufficient to swamp and reverse the local anodic currents, will definitely prevent corrosion, and it is well established, by the experience of owners of pipe-lines, that bacterial corrosion is completely controlled by adequate cathodic protection.

THE APPLICATION OF CATHODIC PROTECTION

General.—

Commercial development, so far as published information shows, has not been extensive, at least in the external protection of ships' hulls. A good deal of attention has, however, been directed to the cathodic protection of the interior of oil-tank ships.

In many respects, the application of cathodic protection to ships' hulls is simpler than to underground pipe-lines. Sea-water forms a constant, homogeneous, highly conducting free-liquid electrolyte; the soil, in contrast to this, is of varying chemical constitution and has a conductivity varying widely with time and place, but always much less than that of sea-water. These differences result in a better "throwing power" in sea-water, because the fall in potential through the electrolyte is so much less; for this

reason, it is much easier to achieve a relatively uniform degree of protection in the sea than underground. Overall operating potentials are also much less.

On the other hand, higher current densities are required in sea-water than underground, because the availability of oxygen is greater, and this entails risk of damage to the paint coats of ships.

Zinc Protectors as a Limited Application of Cathodic Protection.—

The use of zinc protectors on ships, near bronze propellers and other non-ferrous fittings, is probably the best-known application of cathodic protection on a small scale.

The efficiency of zinc protectors has, however, been suspect for many years. It is a common observation that zincs remain active for a short time only and that they fail to give much protection to the hull, even in their immediate vicinity.

Although zinc protectors in their present form are largely discredited, zinc has undoubted advantages as an anode material for certain applications of cathodic protection. Development work is, therefore, in progress to improve the performance of zinc anodes by modifications in design and composition. In order to prevent loss of electrical contact with the hull due to the formation of corrosion scale, a form of zinc protector is being tried which is cast round a projecting steel plate which is bolted or welded to the hull.

Application of Cathodic Protection to H.M. Ships in the Reserve Fleet.—

Normally, a Reserve Fleet ship has to be docked for inspection and painting at least every two years. Cathodic protection offers a means of considerably delaying, and possibly eliminating, the routine dockings.

It is, accordingly, Admiralty policy to apply cathodic protection to Reserve Fleet ships and to a number of fleet auxiliaries which are laid up. Protection is either by the impressed current method when ships are berthed in groups alongside jetties, where shore current is available, or by magnesium anodes when ships are berthed singly at buoys in the stream, or when current is not available.

Before this policy was established, a good deal of experimental work and trials had been undertaken by the Admiralty. The trials were planned to cover extreme cases of newly painted hulls, and of neglected hulls which had had no attention for some years and whose paint was expected to be in poor condition.

Two of the ships with bottom paintwork in good condition were *Algerine* minesweepers, with a wetted surface of about 7,500 sq. ft. Cathodic protection was applied by anodes of magnesium alloy (aluminum 6 per cent, zinc 3 per cent), each being connected to the hull through a 10-amp. shunt for individual current measurement. Current control was, in general, by choice of the number of anodes used. The initial current required by a ship of this size ranged from about 2 to 7 amps. (in these and subsequent trials), rising to an average of about 10 amps. in course of time.

The ships were docked separately after about 14 months' cathodic protection, and in neither case was there any sign of active corrosion. In the first ship docked, the paint was found to be softened and blistered and very easily removable, though a certain amount of this may have been due to the ship being at too high a potential in the first 14 days of the trial. In the other ship, the paint softening was not nearly so marked, but there was a good deal of blistering. There was no ab-

normal rusting at the water-line in the second vessel; but in the earlier case, a belt above the water-line which had been exposed as a result of lightening of the ship during trial, showed a heavy scale of rust and general corrosion. This result suggested the desirability of coating the water-line zone with a paint system less sensitive to softening by cathodic protection.

The outer bottom plating of another ship chosen for trial (a *Hunt*-class destroyer) had not been painted for more than four years. Six magnesium anodes of the usual type were fitted. It was apparent from the hull potential readings that the ship was over-protected, but deliberate excess of current was applied to show the effect on the paint, which could not be expected to have much value after so long a period out of dock. The ship was docked after 2½ years' continuous cathodic protection, when it was found that the wetted area was in excellent condition, with no sign of recent rusting. Wasting of the anodes was remarkably smooth and even, and a useful current had been delivered until practically the whole of the magnesium had been consumed. The hull plating of this ship was galvanized, which somewhat obscures the issue, but the results are, nevertheless, of considerable interest. There was no paint or galvanizing left at the water-line, but immediately above and below there was a layer of scale which was adhering loosely, probably on account of the de-scaling action of prolonged cathodic current. Although there was a little black oxide on the rivet points, they were entirely free from pitting. Special attention was paid to the tightness of the rivets, as the possibility had been suggested that the de-scaling effect of cathodic protection might loosen rusty rivets; no such slackening of the rivets could, however, be detected. Where outer bottom paint remained, it had not been softened by the cathodic current and was in better condition than might have been expected after four years of immersion followed by another 2½ years of cathodic protection. Ungalvanized areas of steel, such as A-brackets and propeller shafts, carried a layer of soft black scale, which was easily removed, showing greyish steel behind with no sign of active corrosion. The presence of this black scale, which analysis showed to be magnetic iron-oxide, was evidence that the galvanized hull had not provided remote protection.

It is of interest to note that the galvanizing was no longer electrochemically active at the beginning of the trial, as was shown by the hull potential of 0.63 volt before cathodic protection was applied. This hull potential was, in fact, no higher than that of an ungalvanized hull which has reached an equilibrium value. Nevertheless, the galvanizing was still serving a useful purpose, as the zinc-corrosion product provided an excellent protective coating. This trial shows that, like the standard zinc protectors, the galvanizing zinc becomes coated with a dense film of its own corrosion product, which protects it from further attack or galvanic activity.

Where it is necessary to lay-up ships in the stream, or where facilities for using impressed current are not available, a practice of using magnesium anodes has been established. Each anode is suspended by rubber-covered electric cable, the inboard end of which is coupled to the hull, preferably through a 10-amp. shunt for current measurement. The anodes are hung deep enough to give a minimum clearance of about 10 ft. from the hull; but, if there is insufficient depth of water, it may be necessary to suspend the anodes from booms from the ship's side

at the maximum depth possible without touching the sea-bed (Fig. 2).

Ships in reserve, wherever possible, are laid-up in groups in basins or alongside wharves where there is access from shore and a shore supply of electricity. This is advantageous for both cathodic protection and dynamic dehumidification, and it leads to economy in man-power.

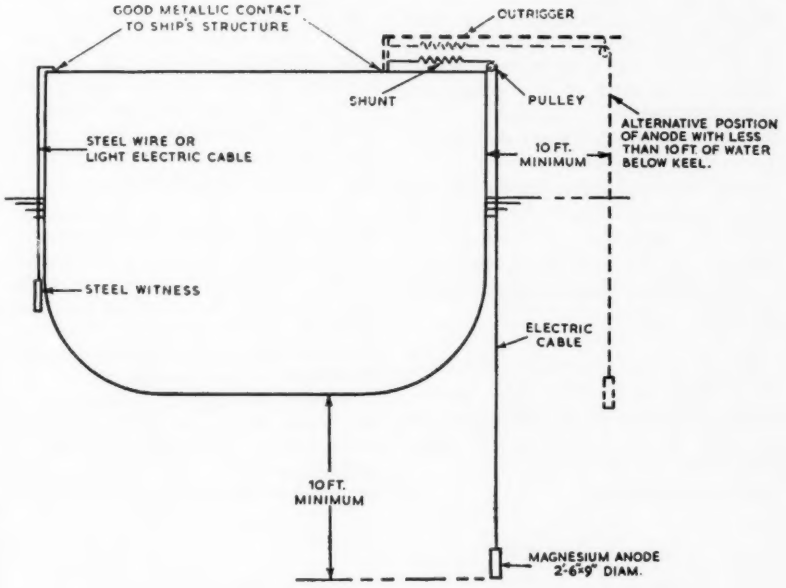


Figure 2.—Magnesium Anodes—Method of Rigging Anode and Steel Witness.

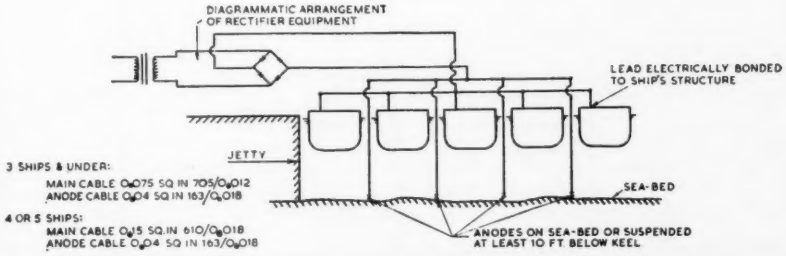

DIAGRAMMATIC ARRANGEMENT OF RECTIFIER EQUIPMENT
LEAD ELECTRICALLY BONDED TO SHIP'S STRUCTURE
JETTY
SEA-BED
3 SHIPS & UNDER:
MAIN CABLE 0.075 SQ IN 705/0.012
ANODE CABLE 0.04 SQ IN 163/0.018
4 OR 5 SHIPS:
MAIN CABLE 0.15 SQ IN 610/0.018
ANODE CABLE 0.04 SQ IN 163/0.018
ANODES ON SEA-BED OR SUSPENDED AT LEAST 10 FT BELOW KEEL

Figure 3.—Circuit Diagram of Impressed-current Method of Cathodically Protecting a Group of Stationary Ships.

The layout of a typical system of the method of applying cathodic protection by impressed current to ships laid up in groups is shown diagrammatically in Fig. 3. Steel anodes formed from old railway lines, about 40 ft. long, are hung between the ships at a depth of 10 ft. below the keel (Figs. 4, 5 and 6). The ships must be insulated from steel jetties, and from ships in the vicinity, which are not receiving protection, but all protected ships in the group are connected together electrically. Current is obtained from shore supply and fed to the steel anodes through transformer/rectifiers sited on the dockside. Provision is made for about 25 amps. for each ship of destroyer or frigate size, but, in general, considerably smaller currents have been found adequate.

The program of cathodic protection of the Reserve Fleet is still in its development stage. It is satisfactory to record, however, that the actual application has not given rise to any unexpected difficulties.

Application of Cathodic Protection to Active Ships.—

The problem of protecting active ships differs from that of static ships in two important ways: —

(a) The anodes must be fixed to the hull and not suspended overboard, as is possible in moored ships.

(b) When under way, the ship requires more current for cathodic protection than when at rest. Variation of current is necessary, therefore, to avoid over-protection (with consequent damage to the paint coatings) when the ship is stationary.

The second of these requirements clearly favors the use of an impressed-current system. Where a power supply is not available, magnesium anodes could be used, fixed to, but insulated from, the hull. Such anodes would require a lead inboard with an adjustable resistance, or, if the current is uncontrolled, the system would have to be employed in combination with paints which are highly resistant to cathodic current. Zinc anodes would be more suitable than magnesium, pro-

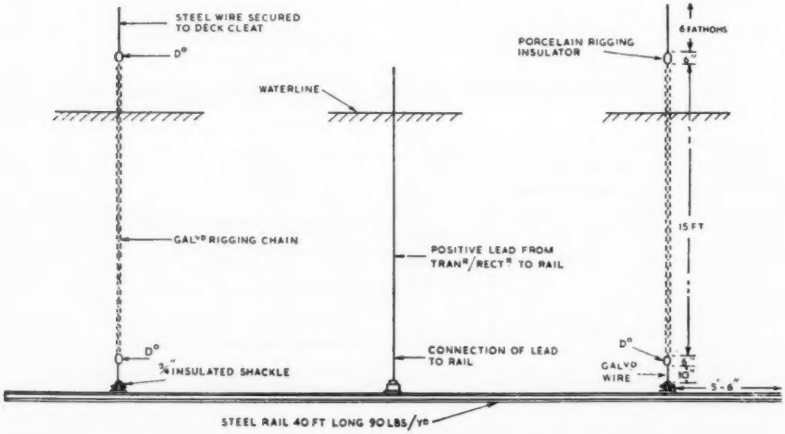


Figure 4.—Impressed Current—Method of Rigging Steel Anode from Stationary Ship.

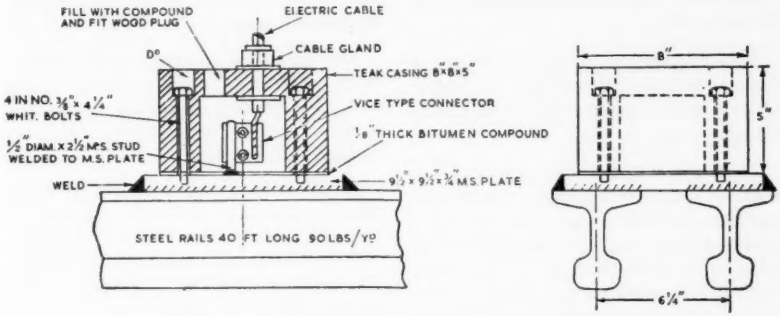

FILL WITH COMPOUND AND FIT WOOD PLUG
ELECTRIC CABLE
CABLE GLAND
TEAK CASING 8"x8"x5"
VICE TYPE CONNECTOR
⅛" THICK BITUMEN COMPOUND
4 IN NO. ⅜" x 4¼" WHIT. BOLTS
½" DIAM. x 2½" M.S. STUD WELDED TO M.S. PLATE
WELD
9½" x 9½" x ¾" M.S. PLATE
STEEL RAILS 40 FT LONG 90 LBS/YD
8"
5"
6¼"

Figure 5.—Impressed Current—Method of Connecting Lead to Steel Anode.

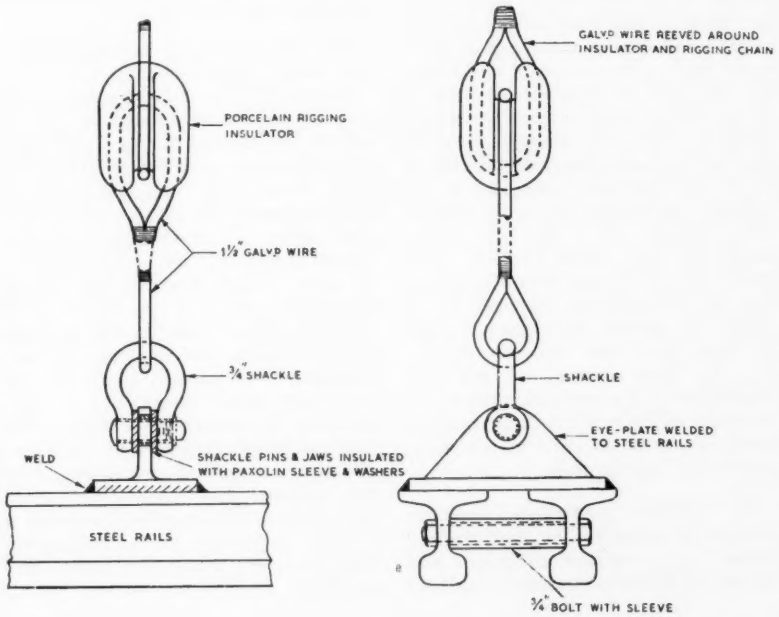


Figure 6.—Impressed Current—Method of Rigging and Insulating Steel Anodes.

vided their permanent activity could be ensured.

When examining the desirability of fitting cathodic protection to active ships, the following are relevant factors:—

(a) Provided that the requisite potential is maintained, protection against corrosion of the external under-water hull is ensured, even when the protective paint has been damaged by abrasion or in any other way. The protection of the water-line area, however, would need separate attention.

(b) While cases of serious corrosion of the external surfaces of outer bottom plates have occurred, these have, to a large extent, been confined to the water-line areas and to other limited areas, such as the fore end, and under the counters of lightly-built vessels of war-time construction. Generally speaking, external corrosion by itself does not normally determine the life of ships' outer-bottom plating, but it can become significant when associated with internal corrosion. The latter would still be a major problem, even if cathodic protection were afforded to the external surfaces, particularly in machinery spaces, and spaces which are inaccessible and subject to dampness. For these reasons, it is not considered likely that any reduction in the thickness of the outer bottom could be accepted, even if external cathodic protection were applied.

(c) Cathodic protection does not prevent or retard fouling. Anti-fouling protection is required, therefore, and the period between docking would still be mainly governed by the life of anti-fouling composition.

(d) Painting of the outer bottom with protective compositions would still be necessary if cathodic protection were applied, in order to avoid the use of high current densities.

(e) Savings in time, cost and labor during dockings may be expected if cathodic protection were applied, owing to the elimination of scaling of the hull, except at the water-line, and to reduction in repairs and rivet replacements due to corrosion.

(f) Slight additional weight and resistance, with consequential decrease in speed and endurance, might be involved by fitting cathodic protection to existing operational ships.

The Application of Cathodic Protection during Fitting-out.

Although so far not extensively employed in this connection, the use of cathodic protection during the fitting-out period is a very desirable aim. In many cases, ships under construction have suffered very serious outer-bottom corrosion in the fitting-out basin. Points to be considered when deciding to apply cathodic protection during fitting-out are:—*(a)* The ship may be moved to different berths, *(b)* the draft and wetted area will increase, and consequently the current demand, and *(c)* other ships alongside will steal some of the protective current. The first two points suggest that, for a single ship, magnesium anodes would be the simplest technique. Operational difficulties would largely disappear if cathodic protection during fitting-out were generally adopted as a standard practice.

CONCLUSION

The primary aim of this paper has been to present the principles and technics of cathodic protection in sufficient outline to indicate the advantages and limitations of the process in its application to ships' hulls. In this

connection, cathodic protection is generally recognized to be most economically employed as complementary to protective coatings rather than as a substitute. The normal preventive measures against the corrosion of ships' outer bottoms have undoubted limitations; the best of coatings are liable to have initial imperfections and to develop defects in service. Cathodic protection offers a reliable means of covering these deficiencies and maintaining immunity from corrosion.

No attempt can be made within the limits of the present paper to deal adequately with the economic aspects of cathodic protection. The cost of installation and the savings effected depend on a variety of factors, but it is apparent, even from general considerations, that, in the application of cathodic protection to ships, savings in replacement of rivets and corroded plating, as well as reduction in the cost of dockings and bottom cleaning, may outweigh the cost of applying this process.

As the basic fact becomes more widely known—that it is possible, by this means, to prevent completely the corrosion of iron and steel in seawater, even when in contact with other metals—it is believed that there will be a trend towards a much wider use of cathodic protection for all manner of metal structures which are inmersed, permanently or intermittently, in seawater.

Official U.S. Navy Photograph

USS *FORRESTAL*

AN INVESTIGATION OF THE FORCES AT THE CONNECTION OF A CIRCULAR PLATE AND AN AXIALLY LOADED CYLINDER

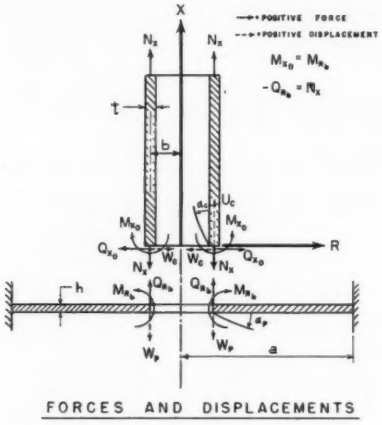
LEOPOLD DeMARINIS

THE AUTHOR

was born July 29, 1924. Attended Haaren High School of Aviation Trades and received Bachelor of Aernoautical Engineering Degree from New York University in 1947; joined Foster Wheeler Corporation in that year as stress analyst in Special Design Department. Supervised design and drafting of pressure vessels, equipment specification and selection, was assistant contract supervisor and project engineer until joining the Company's Nuclear Engineering Department in 1954. Received Master of Science Degree in Applied Mechanics from Polytechnic Institute of Brooklyn in June 1955. Present duties include stress analysis for Foster Wheeler Corporation's Homogeneous Reactor Project and project engineering of research reactors.

This investigation is based upon a portion of the author's thesis submitted to the Polytechnic Institute of Brooklyn in partial fulfillment of the requirements for the degree of Master of Science in Applied Mechanics under the guidance of Dr. J. Kempner.

Various studies have been made both here and abroad, on the problem of reinforced annular plates. One such recent investigation by Mr. Irving Granet appeared in the May 1955 issue of this journal. Each analysis has been made under the assumption that the angle between the cylindrical reinforcement and the annular plate remains the same, before and after loading. This approach will yield approximate values for the shear and moments, induced by the loading, at points where the cylinder meets the plate. The degree of approximation is dependent upon the efficiency of the junction between the cylinder and the plate. Even for the case of the cylinder fillet welded to the plate, R. J. Roark in reference 1 indicates the best probable degree of fixation to be about 90%. Furthermore, E. O. Holmberg and K. Axelson in their analysis, reference 2, indicate a lesser degree of fixation for a welded attachment. If the connection between the cylindrical hub and the annular plate was welded, screwed, riveted or rolled there would result a very different stress distribution in each case. When the cylinder is joined to the plate by means of an elastic member, such as a weld, the angle between the cylinder and plate will not be the same before and after loading.



FORCES AND DISPLACEMENTS

Figure 1

It is the purpose of this paper to illustrate the effect upon the connecting moment M_{R_b} when the cylinder is axially loaded (see figure 1), by the change in the angle between the cylinder and plate and to show that the effect on this moment by the change in the angle is small.

In addition to the usual basic assumptions made in linear shell theory, it is assumed that the generatrix of the unloaded cylinder is normal to the plane of the plate, whereas in the loaded condition the slope of the generatrix at X=O, adjusted by a fixation factor, is equal to the slope of the plate.

We shall treat the plate and cylinder separately. The plate is to be analyzed under the action of unknown forces Q_{R_b} and M_{R_b}, and the cylinder under the action of the unknown M_{x_o}, Q_{x_o} and the applied load N_X. By relating the slope of the cylinder to that of the plate, where the two meet, we can determine the magnitude of the unknown moments.

CIRCULAR PLATE

For the axi-symmetric loaded and deformed plate we take the differential deflection equation in the form derived by S. Timoshenko (reference 3, pg. 58).

$$\frac{d}{dR}\left[\frac{1}{R}\frac{d}{dR}\left(R\frac{dw_p}{dR}\right)\right] = \frac{P}{2\pi R D_p} \quad \ldots\ldots (1)$$

where $P = 2\pi b Q_{R_b}$

Boundary Conditions on Plate

At R = a

$$w_p = o \quad \ldots\ldots (2)$$

$$\frac{dw_p}{dR} = o \quad \ldots\ldots (3)$$

At $R = b$ $$M_{R_b} = -D_p\left[\frac{d^2w_p}{dR^2} + \frac{\nu}{R}\frac{dw_p}{dR}\right] \quad \ldots\ldots (4)$$

These boundary conditions correspond to a plate rigidly fixed at its outer periphery where its slope and deflection are zero. The perimeter of the hole is unsupported and acted upon by the moment M_{R_b} and the shear force Q_{R_b}.

Successively integrating expression (1) we obtain the general expression for the slope and deflection respectively.

$$\frac{dw_p}{dR} = \frac{RP}{8\pi D_p}\left(2\ln\frac{R}{a} - 1\right) + \frac{C_1 R}{2} + \frac{C_2}{R} \quad \ldots\ldots (5)$$

$$w_p = \frac{R^2 P}{8\pi D_p}\left(\ln\frac{R}{a} - \frac{1}{2}\right) + \frac{C_1 R^2}{4} + C_2 \ln\frac{R}{a} + C_3 \quad \ldots\ldots (6)$$

On differentiating (5) with respect to R we obtain

$$\frac{d^2w_p}{dR^2} = \frac{P}{8\pi D_p}\left(2\ln\frac{R}{a} + 1\right) + \frac{C_1}{2} - \frac{C_2}{R^2} \quad \ldots\ldots (7)$$

The constants of integration must be determined from the boundary conditions stated in (2), (3) and (4), hence substituting (5), (6) and (7) into these boundary conditions we find:

$$C_1 = -\frac{2b^2 M_{R_b}}{D_p[a^2(1-\nu) + b^2(1+\nu)]} - \frac{P}{4\pi D_p}\left[\frac{2b^2\left\{(1+\nu)\ln\frac{b}{a} + 1\right\}}{a^2(1-\nu) + b^2(1+\nu)} - 1\right] \quad \ldots\ldots (8)$$

$$C_2 = \frac{a^2 b^2 M_{R_b}}{D_p[a^2(1-\nu) + b^2(1+\nu)]} + \frac{P}{4\pi D_p}\left[\frac{a^2b^2\left\{(1+\nu)\ln\frac{b}{a} + 1\right\}}{a^2(1-\nu) + b^2(1+\nu)}\right] \quad \ldots\ldots (9)$$

$$C_3 = \frac{a^2 b^2 M_{R_b}}{2D_p[a^2(1-\nu) + b^2(1+\nu)]} + \frac{P}{16\pi D_p}\left[\frac{2a^2b^2\left\{(1+\nu)\ln\frac{b}{a} + 1\right\}}{a^2(1-\nu) + b^2(1+\nu)} + a^2\right] \quad \ldots (10)$$

Upon substituting the values of these constants into equation (5), with $R=b$, we have the slope of the plate at its inner boundary under the action of a uniformly distributed load.

$$\alpha_p = \left(\frac{dw_p}{dR}\right)_{R=b} = \frac{b(a^2-b^2)M_{R_b}}{D_p[a^2(1-\nu) + b^2(1+\nu)]} + \frac{P}{4\pi D_p}\left[b\ln\frac{b}{a}\left\{1 + \frac{a^2-b^2}{\left(\frac{1-\nu}{1+\nu}\right)a^2 + b^2}\right\}\right.$$

$$\left. + \frac{b(a^2-b^2)}{a^2(1-\nu) + b^2(1+\nu)}\right] \quad \ldots\ldots (11)$$

CIRCULAR CYLINDER

We take for an inward radial deflection of the cylinder the form of the equation derived by S. Timoshenko (reference 3 page 399)

$$w_c = C_4 \sin(\beta x)\sinh(\beta x) + C_5 \sin(\beta x)\cosh(\beta x) + C_6 \cos(\beta x)\sinh(\beta x) + C_7 \cos(\beta x)\cosh(\beta x) + f(x) \quad \ldots\ldots (12)$$

Boundary Conditions on the Cylinder

The four constants in equation (12) must be determined from the boundary conditions at the ends of the cylinder, which are:

at $x = o$

$$(w_c)_{x=o} = o \quad \ldots\ldots (13)$$

$$(M_X)_{x=0} = M_{X_o} = -D_c\left(\frac{d^2 w_c}{dx^2}\right) \quad \ldots\ldots (14)$$

at $x = L$

$$(W_c)_{x=L} = o \quad \ldots\ldots (15)$$

$$(M_x)_{X=L} = o \quad \ldots\ldots (16)$$

These boundary conditions correspond to a cylinder simply supported at both ends with applied axial tensile loads and an applied radial moment at one end.

Evaluation of $f(x)$

$f(x)$ represents the radial displacement of the unrestrained cylinder and is the particular solution for the general deflection equation (12), for the case of uniform load. Neglecting the effect of the change in curvature, after deformation, and using Hooke's Law, we find:

$$\varepsilon_x = \frac{1}{E}(\sigma_x - \nu\sigma_\theta) \quad \ldots\ldots (17) \qquad \varepsilon_\theta = \frac{1}{E}(\sigma_\theta - \nu\sigma_x) \quad \ldots\ldots (18)$$

since $\sigma_\theta = o$ $\qquad \varepsilon_x = \dfrac{\sigma_x}{E} \quad \ldots\ldots (19)$

and $\qquad \varepsilon_\theta = -\dfrac{\nu\sigma_x}{E} \quad \ldots\ldots (20)$

$$\varepsilon_\theta = \frac{\partial v}{\partial \theta} - \frac{w_c}{b} = -\frac{\nu\sigma_x}{E}$$

$$w_c = \frac{\nu\, b\, \sigma_x}{E} \quad \ldots\ldots (21)$$

This deformation would be constant for the entire length L if the cylinder were not radially constrained. The applied load P for this case is tensile and shall be denoted by

$$P = \int_o^{2\pi} N_x \, d\theta \quad \ldots\ldots (22)$$

which is the total applied load.

The axial stress σ_x, a constant, is:

$$\sigma_x = \frac{P}{2\pi b t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

Substituting σ_x into (21),

$$w_c = \frac{\nu P}{2\pi E t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

hence

$$f(x) = \frac{\nu P}{2\pi E t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

which is a constant.

Evaluation of Arbitrary Constants

Inserting (12) into (13) we see immediately that

$$C_7 = -f(x) = -\frac{\nu P}{2\pi E t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Differentiating (12) with respect to X, we arrive at the slope of the cylinder at any point along its length.

$$\frac{dw_c}{dx} = \beta \Big\{ (C_4+C_7)\cos(\beta x)\sinh(\beta x) + (C_4-C_7)\sin(\beta x)\cosh(\beta x$$

$$+ (C_5+C_6)\cos(\beta x)\cosh(\beta x) + (C_5+C_6)\sin(\beta x)\sinh(\beta x) \Big\} \quad \ldots\ldots (27)$$

Differentiating (27) and multiplying by the flexural rigidity, D_c, of the cylinder, we get the moment expression

$$-D_c\frac{d^2w_c}{dx^2} = -2\beta^2 D_c \Big[C_4\cos(\beta x)\cosh(\beta x) + C_5\cos(\beta x)\sinh(\beta x)$$

$$- C_6\sin(\beta x)\cosh(\beta x) - C_7\sin(\beta x)\sinh(\beta x) \Big] = M_x \ldots\ldots\ldots\ldots (28)$$

Expressions (12) and (28) evaluated for X = L become respectively:

$$(w_c)_{x=L} = C_4\sin(\beta L)\sinh(\beta L) + C_5\sin(\beta L)\cosh(\beta L)$$
$$+ C_6\cos(\beta L)\sinh(\beta L) + C_7\cos(\beta L)\cosh(\beta L) + f(x) \ldots\ldots\ldots\ldots (29)$$

$$(M_X)_{X=L} = -2\beta^2 D_c \Big[C_4\cos(\beta L)\cosh(\beta L) + C_5\cos(\beta L)\sinh(\beta L)$$

$$- C_6\,\mathrm{siin}(\beta x)\cosh(\beta L) - C_7\sin(\beta L)\sinh(\beta L) \Big] \ldots\ldots\ldots\ldots (30)$$

Expression (28) evaluated for X = O becomes:

$$(M_X)_{X=0} = -2\beta^2 D_c C_4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

Since C_7 and $f(x)$ are known, expressions (28), (29) and (30) reduce to three equations in three unknowns. After enforcing boundary conditions (15), (16) and (14) respectively on these reduced expressions we can easily solve for C_4, C_5, and C_6.

$$C_4 = -\frac{M_{x_0}}{2\beta^2 D_c} \qquad \ldots\ldots (32)$$

$$C_5 = \frac{1}{2EtA}\left[12(1-\nu^2)\sinh(\beta L)\cosh(\beta L)M_{x_0} + \frac{\nu P \sin(\beta L)}{\pi}\left\{\cos(\beta L) - \cosh(\beta L)\right\}\right] \qquad \ldots\ldots (33)$$

$$C_6 = \frac{1}{2EtA}\left[\frac{12(1-\nu^2)\sin(\beta L)}{\beta^2 t^2 \cos(\beta L)}\left\{A - \cosh^2(\beta L)\right\}M_{x_0} + \frac{\nu P}{\pi \cos(\beta L)\sinh(\beta L)}\left\{\sin^2(\beta L)\cosh(\beta L)\left[\cosh(\beta L) - \cos(\beta L)\right] + A\left[\cosh(\beta L)\cos(\beta L) - 1\right]\right\}\right] \qquad \ldots\ldots (34)$$

where $A = \sin^2(\beta L)\cosh^2(\beta L) + \cos^2(\beta L)\sinh^2(\beta L)$ $\ldots\ldots (35)$

Substituting constants C_5 and C_6 into equation (27) with the value of $X=O$, we arrive at the slope of the cylinder at its junction with the plate.

$$\alpha_c = \left(\frac{dw}{dx}\right)_{x=0} = \frac{6(1-\nu^2)M_{x_0}}{A\beta E t^3 \cos(\beta L)}\left[\cosh(\beta L)\left\{\cos(\beta L)\sinh(\beta L) - \sin(\beta L)\cosh(\beta L)\right\} + A\sin(\beta L)\right] - \frac{\nu\beta P}{2A\pi Et\cos(\beta L)\sinh(\beta L)}\sin(\beta L)\left\{\cosh(\beta L) - \cos(\beta L)\right\}\left\{\cos(\beta L)\sinh(\beta L) - \sin(\beta L)\cosh(\beta L)\right\} - A\left\{\cos(\beta L)\cosh(\beta L) + 1\right\}\Bigg] \qquad \ldots\ldots (36)$$

Now that we have determined the slope of the cylinder as a function of the applied load P and the unknown moment M_{x_0}, there remains the task of solving for this unknown connecting moment. We see that this moment can be evaluated by means of the following relation:

$$f_1\left(\frac{dw_c}{dx}\right)_{x=0} = -\left(\frac{dw_p}{dR}\right)_{R=b} \qquad \text{.....(37)}$$

Where f_1 is a constant inserted to take into account relative rotation of the plate and shell.

For an absolutely rigid connection of the cylinder to the plate, that is, when the angular relations hold true before and after loading, the value of the factor f_1 can only be unity. This is comparable to the case of an elastic cylinder with a perfectly rigid attachment to an elastic member; the assumption made by Granet and others. Regardless of the type or efficiency of attachment of the cylinder to the plate, the edge of the hole will be held in one plane, since u_c (see figure 1) is obviously a constant. If the attachment of the cylinder to the plate is not rigid, the angle between them would no longer be $\pi/2$ and the moment M_{x_0} at the edge of the hole would tend to diminish (see figure 2). The effect of this relaxation would also tend to increase the absolute value of the slope of the plate in a radial direction at R = b.

Evaluation of Unknown Connecting Moment

Inserting expressions (36) and (11) into (37) relates the slope of the cylinder to that of the plate at their junction, enabling one to solve for the unknown connecting moment

$$M_{x_0} = \frac{P}{\pi}\left[\frac{\nu\beta f_1 t^2}{12(1-\nu^2)\sinh(\beta L)}\left\{\frac{B}{A}\sin(\beta L)\left[\cosh(\beta L) - \cos(\beta L)\right]\right.\right.$$

$$\left.\left. - \cos(\beta L)\cosh(\beta L) + 1\right\} - \frac{t^3\cos(\beta L)}{2h^3}\left\{b\ln\frac{b}{a}\left[1 + \frac{(1+\nu)(a^2-b^2)}{a^2(1-\nu)+b^2(1+\nu)}\right.\right.\right.$$

$$\left.\left.\left. + \frac{b(a^2-b^2)}{a^2(1-\nu)+b^2(1+\nu)}\right\}\right] \div \left[\frac{f_1 B}{\beta A}\cosh(\beta L) + \frac{f_1\sin(\beta L)}{\beta}\right.$$

$$\left. + \frac{2bt^3\cos(\beta L)(a^2-b^2)}{h^3[a^2(1-\nu)+b^2(1+\nu)]}\right] \qquad \text{.....(38)}$$

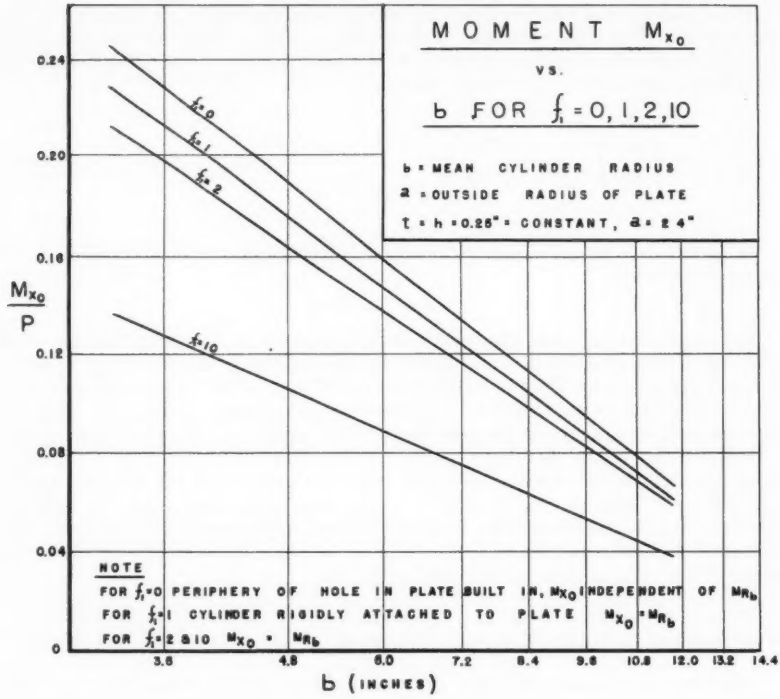


Figure 2

where $B = \cos(\beta L)\sinh(\beta L) - \sin(\beta L)\cosh(\beta L)$ and A has been defined by expression (35).

We can best analyze the effect of f_1 and various thickness ratios t/h on this connecting moment through the results of several numerical examples. The variation in M_{x_0} for several values of f_1 while t/h is held constant, is plotted in figure 2. The variation in M_{x_0} for several values of t while f_1 and h are held constant, is plotted in figure 3.

The ideal case of an elastic cylinder rigidly attached to an elastic plate was investigated and then the rigid attachment was progressively weakened. This corresponds to assigning the value of 1 to f_1 in equation (38) and then subsequently increasing it.

Analyzing the results for a given value of b, figure 2, we see that as the junction of the cylinder to the plate becomes weaker, (f_1 increasing), the moment decreases. If one pursues the weakening-of-the-junction concept to the limit

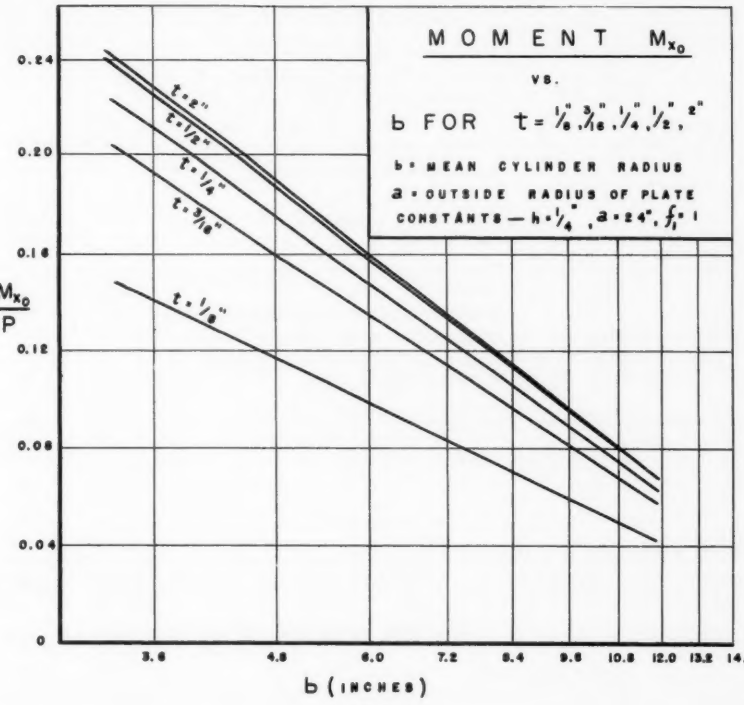


Figure 3

he would arrive at a simply supported boundary at R=b for which the connecting moment would be zero. For a given value of f_1 we see that the connecting moment M_{x_0} decreases as b increases. In this instance the efficiency of the junction remains constant and it is the change in the cylinder flexibility which causes the moment decrease. The increase in the cylinder radius increases its flexibility quite rapidly, thereby necessitating a smaller moment in order to meet the prescribed slope conditions. This phenomenon is in good agreement with the experimental work done by R. J. Roark in reference 1.

Observing the results in figure 3 we see that for a given value of b, the moment M_{x_0} decreases when the thickness t decreases. This is analagous to increasing the flexibility of the cylinder while that of the plate remains constant.

For a given thickness t the connecting moment decreases as the value of b increases. Here again it is the increase in the cylinder flexibility which causes the decrease in the moment M_{x_0}.

If one accepts R. J. Roark's opinion that the best probable efficiency for a fillet welded connection is about 90%, ($f_1 = \frac{1}{0.90} = 1.11$); then the effect on M_{x_0} of the change in angle between the cylinder and plate is small, less than 1%.

NOMENCLATURE

W_p	transverse deflection of plate
W_c	radial deflection of cylinder
u_c	axial deflection of cylinder
b	mean radius of cylinder
a	outside radius of plate
t	wall thickness of cylinder
h	thickness of plate
α_p	slope of the plate at R=b
α_c	slope of the cylinder at R=b
C	constant of integration
ln	natural logarithm
P	total applied load, see equation (22)
M_{R_b}	radial moment on plate at R=b
M_{x_b}	radial moment on cylinder at R=b
D_p	flexural rigidity of plate
D_c	flexural rigidity of cylinder
ν	Poisson's ratio
f_1	fixation factor

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ENGINEERING ABSTRACTS

COPIES OF ABSTRACTED ARTICLES CANNOT BE FURNISHED BY THIS SOCIETY. REQUESTS FOR THESE SHOULD BE MADE TO THE ORIGINAL PUBLISHER OR TO THE SOCIETY WHICH SPONSORED THE PAPER.

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60–55	Jet Noise
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NOTE: "*" indicates that the paper was prepared to be presented at the Joint Conference on Combustion, arranged by the American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y., and the Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, S. W. I., England, held in Boston, Mass. from Wednesday 15th June, to Friday 17th June, 1955, and in London, England from Tuesday 25th October to Thursday 27th October, 1955.

28-55 "Marine Machinery of the Immediate Future from the Shipowner's Point of View"—J. E. Church; The Institute of Marine Engineers Transactions, V. LXVII, n. 7, July, 1955, pp 227–238. Cost of constructing and operating merchant vessels with different propulsion plants, both pre-war and new, is discussed. The trend now taking place in size of the British Merchant Fleet with respect to world tonnage replacement is shown. Selection of best propulsion machinery that will bridge the interval until atomic propulsion is available and within reach depends on these problems:

1. High price of building is such that
   (a) smaller engines must be considered and
   (b) the prime mover should be divided in two units.
2. Depreciation and loss of interest approach fuel cost. Reduction in initial cost is to be considered.
3. Cheaper and lighter machinery may result in increased repair and maintenance and a reduction in reliability.
4. Heavier and cheaper fuels now used in motor ships are having an adverse effect on reliability, maintenance and repair cost.

Four propulsion plants for a 10,000-ton cargo vessel of 5,300 s.h.p. for a speed of 14 knots were presented in an analysis of machinery of the immediate future. These plants are:

1. Twin two-stroke cycle single-acting medium-speed geared diesels.
2. Enclosed crankcase reversible double-compound steam engine in conjunction with non-reversible supercharged four-stroke cycle single-acting diesel.
3. Triple expansion steam reciprocating engine taking steam from a water tube boiler in conjunction with twin four-stroke cycle single-acting non-reversing turbo-charged fast-running diesel engines.
4. Ahead and astern single casing double reduction geared steam turbine in conjunction with an open cycle gas turbine.

Comparative daily operating costs of a 10,000-ton 14 knot cargo liner with various machinery plants are as follows:

PLANT COST £ PER DAY

Item	Twin Geared Diesel	Diesel and Steam	Triple Exp. Steam and Diesel	Gas Turbine and Steam	Steam Turbine	Opposed Piston
Fuel	225	252	257	230	271	217
Wages	74	70	70	68	68	74
Repairs	19	16	16	13	11	18
Depreciation ...	98	76	72	83	91	97
Total	416	414	415	394	441	406

29-55 "Rigidity—The Unknown Cost-Reduction Factor"—C. A. Bierlein. Mechanical Engineering, V. 77, n. 9, Sept. 1955, pp 774–777. Failure or maloperation of many machine parts can be attributed to lack of rigidity. This lack of rigidity may be found in the machining equipment, gages or in some element of the finished machine. Good designs cannot compensate for poor machining operations due to faulty equip-

ment or to inspection techniques that use instruments that do not have sufficient rigidity to assure reliable measurements. Inspection tools that sacrifice rigidity to achieve streamlined appearance can result in costly errors. Costly surface finishes are often specified where they are not required. A particular machine part cost would increase 22 percent by reducing finish from 32 to 16 microinches and 38 percent by reducing from 32 to 4 microinches. Temperature affects on sizes and shapes of stainless steel and bronze parts make constant temperature machining and measurement essential. Cost increases are incurred by lack of stiffness that requires additional machining operations.

30-55 "Combustion Products and Wear in High-Speed Compression Ignition Engines, with particular Reference to the Use of Lower Grade Fuels"—W. T. Lyn. Accelerated wear of upper liners and piston assemblies usually accompanies the use of lower grade fuels. Mechanism by which this wear takes place has not been clearly defined. Data presented covers the nature and causes of wear and their relation to combustion products. Initial step included a survey of published literature which indicated that the effect of sulphur in fuel must be considered in terms other than direct condensation of sulphuric acid. It is not yet established that direct condensation occurs under extended running at light loads, cold starting or excessive cooling. Inter-reaction of SO_3 and formation of carbon and other factors may have bearing on wear. The type of corrosion experienced with residual oils in gas turbines does not occur in diesels. Material presented includes: the fuels and test engine; the extent of corrosion by combustion products; tentative theory of wear by abrasive particles; test with carbon-scraping ring; rates of carbon deposition from class A and B fuels; sulphur and acid contents of carbonaceous deposits; and structure of carbonaceous deposits. This investigation does not show that acid formed from the sulphur is responsible for high wear rates. Charts, illustrations, tables and bibliography included.

31-55 "Maintenance Welding and Cutting Operations on Radioactive Process Equipment"—E. B. Lavelle and J. M. Fox, Jr.; The Welding Journal, V. 14, n. 8, Aug. 1955, pp 731–740. Problems of plant maintenance where radioactive equipment is used are discussed. Hazards involved with this equipment can be minimized. Safety records at the Hanford Atomic Products Operation show over 9,400,000 man-hours worked from February through September 1954 without a disabling injury. At this plant the major injury severity rate during 1954 was 19.0. Average for all industry was 830 in 1953. Maintenance experience often dictates the equipment design. Careful control of each step in the maintenance is mandatory. All steps are listed, analyzed and studied in relation to the end result.

An example of a welding job is outlined briefly as follows:

1. Radioactive pipe fails and must be replaced.
2. Radiation monitor surveys area to set work time limits at certain distances.

3. Proper protective clothing is selected.
4. A mock-up of the job is prepared and operation rehearsed until workers understand all details.
5. Weather conditions, wind can affect work.
6. Work area and equipment are decontaminated where possible.
7. Pipe is removed for welding.
8. Welding equipment checked.
9. Work started and continues until time limit.
10. Welder leaves job.
11. Work progress reported to next welder.
12. Procedure continues until work is done.
13. Weld inspected and tested.
14. Area cleaned up and surveyed.
15. Equipment put back in service.
16. Workmen are surveyed for radioactive contamination.
17. Equipment used is decontaminated if possible.

Careful planning, proper design, remote maintenance operation and protective clothing and equipment are all contributing to safe welding and cutting on radioactive equipment.

32-55 "Hard-Facing Process Permits Reclaiming of Pipeline Flow—Control Valves"—The Welding Journal, V. 34, n. 6, June 1955, p. 573. Process followed consists of reclaiming valve body seating surface and plug. Seating surface is arc welded and ground oversize. The plug is: (1) reworked to remove original chrome-plated tapered seating surface, (2) cavities and surface imperfections are arc welded and rough machined, (3) surface is grit blasted, acid dipped, steam cleaned and air blast dried, (4) hard facing alloy pistol sprayed on plug while rotating in lathe, (5) heated with torch to 1900° F to fuse overlay, (6) finish ground to match valve body.

33-55 "The Pametrada Progress Report for 1954"—The Shipbuilder and Marine Engine-Builder, V. 62, n. 567, August 1955, pp 510-511. Research undertaken by Pametrada covers a wide range. High-temperature steam turbine trials (Pamela) were conducted to obtain fundamental design data. Shrouds of different material were tried. Shroud damage repair by welding was tried but was unsatisfactory. New test instrumentation changes were made to obtain reliable power and efficiency results. Consistent casing distortions were obtained in controlled steam temperature tests. New combustion equipment is under test. Condenser development was completed. Gas turbine research included the liquid-cooled high temperature unit. The complete turbine will be erected about the middle of 1955.

34-55 "Application of Electronic Probes to Measurements in Turbulent Flames." Bela Karlovitz. Steam boilers, gas turbines, diesel engines and many industrial processes depend on turbulent flames. Measurement of turbulent flame properties requires special methods. The electronic probe can be used to: determine thickness of the turbulent flame brush; show instantaneous combustion wave; reveal discontinuities of the combustion wave surfaces. This probe is based on the

higher ionization density existing in the combustion wave than that in the hot combustion gas. The probe can measure: the distribution of the fraction of time which the instantaneous combustion wave spends in any small interval of the flame brush; the thickness of the flame brush; the fullness of the flame. This probe is now being applied in the development of practical combustion systems. It was developed at the U. S. Bureau of Mines under Office of Naval Research Contract NAonr 25-47, NR 098117.

35-55 "Plastics—Insulated Cables Prove Themselves"—R. B. McKinley and C. H. Seaberg. General Electric Review, V. 58, n. 4, July 1955, pp 33-35. Polyvinylchloride plastics insulations are highly resistant to sunlight, oil and chemicals. They require no protective coating and are generally superior to rubber insulations. High dielectric of plastic reduced wall thickness of insulation from 47 to 31 mils. On large cables savings can be up to 100 mils. Polyethylene is principally used for long-distance communication lines because of its lower specific inductive capacity. Polyvinylchloride insulation is used in communication cable, building wire, machine tool wire, radio hook-up wire, aircraft cable, and many other applications. It has a temperature range of operation from 60 to 105 C. Some 60 million pounds of polyvinylchloride is consumed annually by the wire and cable industry.

36-55 "Army's New Shallow Water Craft"—M. O. Waugh. Diesel Progress, July, 1955, pp. 42-43. Work of the U. S. Army's transportation Research and Development Command at Fort Eustis, Virginia, has resulted in two shallow water craft for use in moving supplies on inland waterways. These craft include a 51-ft. selfpropelled plastic barge and a tow boat. The plastic barge B SPI 6671 can push or pull other barges. It has a light draft of 12 in., loaded with 5 ton 21 in. Speed with a tow is 7.5 mph and 14 mph without a tow. This barge is powered with two GM 671 diesel engines. It was designed by W. R. Chance Associates. Construction is of a "sandwich" type material, using an inner and outer skin of polyester resin reinforced by layers of fibreglass cloth. Between these skins is a cellular honeycomb material of cotton duck impregnated with phenolic resin. The barge is made up of two main sections for rail shipment. The towboat STI 2195 is: welded steel construction, molded length 96 ft., breadth 23 ft., depth 4.5 ft., accommodations for ten, fuel capacity 11,300 gal., operating speed in 5-ft. pool water is 7.5 mph, powered by three 170 h.p. Caterpillar marine diesels, three 36 in. propellers, two GM diesels drive Delco generators.

37-55 "Glass Fibre Hull for 54 Foot Yacht"—The Marine Engineer and Naval Architect, V. 78, n. 944, July 1955, pp. 276–277. A 54 foot sea going yacht has been constructed of Deborine, a polyester resin reinforced with glass fibre. The vessel is powered with two 200 b.h.p. Rolls Royce diesels. The shell is approximately ⅜ in. thick. It is reinforced by 1½ in. deep hollow frames of "top hat" section at 12 in. interval. The hull is a single structure which will not develop leaks in bad weather due to working.

38-55 "Changing Pattern of Maintenance and Repair of the Machinery of the Fleet"—Rear Admiral John E. Cook, R.N. Presented before Summer Meeting, Institution of Mechanical Engineers, Southampton, July 7, 1955. An analysis of fleet maintenance and repair over the past forty years is presented on main and auxiliary machinery of Her Majesty's ships. "Maintenance" is defined as day-to-day servicing, prevention or reduction of rate of wear and tear, and rectification of such wear and tear as does take place by the ship's force. "Repair" is specified as the rectification of wear and tear and damage that is beyond capacity of ship's force to handle.

Following the period 1939-1945 the need to develop detailed maintenance plans and tie them in closely with operations was felt. Internal combustion engines were recognized as items to be reduced in number and type to a minimum by standardization. War's end engines were divided into: (1) smallest number that would continue in operation until Admiralty Standard Range engines, 6 b.h.p. to 2000 b.h.p. were brought into use; (2) Those engines that would not be replaced. Admiralty Standard Range One engine covers 500-2000 b.h.p. by varying number of cylinders and degree of supercharging. Commercial designs will be used for some low power requirements. Satellite overhaul establishments have been set up outside each home dockyard. Complete overhauls are made here on different type on a batch-line principle.

Spare parts distributing centres were established in many locations. They are fed from a parent establishment. Preservation, identification and packaging specification, inter-service was developed and placed in use.

Naval service craft bases, manned by the Navy, relieve dockyards of much work in peace time and contribute to adequate maintenance in wartime.

New developments and their application to the fleet have resulted in many improvements. These include: plastic lagging of proper thickness to hot surfaces, changes in ventilation systems based on instrumental examination, improved habitability in machinery spaces, provision of fuel oil, tank and bilge-cleaning vessels, water washing for external boiler cleaning, and use of Admiralty evaporator compounds to decrease frequency of cleaning.

New methods and techniques include: "clean" shops for precision work; chemical descaling; electrolytic derusting; shaving main gears in place aboard ship; build up of worn parts by metal deposition; functional testing of steam machinery after refit or overhaul. New and complicated machinery is more difficult to service. Survey shows 60 per cent more man-hours needed to refit feed pumps and other items in 1951 than in 1929. Future policy requires preventive maintenance schedules for various classes of ships. These schedules can be revised based on experience. Dockyard repair policies include consideration of a refit cycle for each class of ship.

39-55 "Thermal Power Plants and Generators"—The Brown Boveri Review, V. 42, n. ½, Jan.-Feb. 1955, pp. 4–19. Progress on gas turbines, steam turbines, velox steam generators, turbo generators, and diesel generator sets are discussed. Gas turbine experience includes: (a) a 5-MW unit gave trouble-free service, without any repairs or replacements for 12,300 hours; (b) a 5.4-MW unit has operated for over 22,000 hours; (c) the combined output of two gas turbine driven generator sets at Beznau was more than 75 million KWH during period Nov. 1, 1953 to March 1954; (d) maintenance cost for gas turbine plant even when burning heavy fuel is no more than 0.12 Swiss centimes/KWH, about one half maintenance cost in large steam driven plants. Steam turbine: (a) construction is now underway on a 170 kg/cm² abs and 650°C; (b) almost all large-output condensing turbines are designed for reheating. Velox steam generators: (a) units can now be constructed for 170 kg/cm² abs, 600° C with capacities up to 150 t/h; (b) a Velox installation with two boilers, each capacity of 90 t/h at 125 kg/cm² abs and 535° C, with total excess output from the two gas turbines of 6 MW and a 55 MW turbo generator would have an overall efficiency of 34%.

40-55 "Combustion Chambers and Control of the Temperature at Which They Operate"—W. Tipler. Rates of heat transfer in gas turbine combustion chambers and methods for maintaining combustion chamber walls at reasonable values to assure satisfactory service are discussed. Aircraft, industrial and marine applications are mentioned. Aircraft combustion chambers are small in diameter and use only light distillate fuels. Radiation rates to primary walls are low. Life is effected by the intense high frequency vibration. Industrial and marine combustion chambers are heavier and much larger and use heavier fuels. Radiant heat flow to combustor walls is intense. Cooling of combustor walls is more severe in these than in aircraft units because of high preheat, in the order of 750° F. Dimensioning of the primary zone is set by heat release rate attainable with available pressure loss. Equations for limiting fuel flow and shroud air velocity are shown. Methods of calculating radiant and convective heat flow rates are given. Construction and cooling the primary zone wall is done by: (1) external convection of mixing air; (2) ceramic coating or lined walls cooled by external convection of mixing air; (3) perforated walls cooled by either or both effusion or internal convection of discrete air bleeds. Main weakness of the swirl type burner is the influence of fuel type on flame emissivity. With efficient combustion of residual fuel blend simple type wall construction is unlikely to be applied in long life gas turbines where output per combustion chamber exceeds 1000 KW. Louvered construction is costly. Refractory construction appears the better choice when life, price and combustion conditions are considered. Tables, curves, diagrams, photographs and references included.

41-55 "H. M. Gunboat 'Grey Goose' "—The Motor Ship, V. XXXVI, n. 425, August 1955, pp. 188–189. The "Grey Goose" completed trials in June and was placed in commission with trials squadron of H.M.S. "Hornet" at Gosport. The vessel is powered with two Rolls Royce gas turbine

engines. Propulsion plant data includes: Design full power rating of each turbine is 5400 s.h.p.; corresponding thermal efficiency 21.5%; fuel is diesel with viscosity 31.5 to 36 Redwood No. 1 at 100°F; specific fuel consumption approximately 0.64 lb./s.h.p./hr.; reversal accomplished by Rotol variable pitch propellers. The gas turbine installation gives an increase in power of about 35% and cuts the weight in half, the original propulsion plant was steam.

42-55 "Diesels in the Arctic"—Mark Ogden. Diesel Progress, June 1955, pp. 40–43. A number of diesel driven generator sets are to be installed along the Distant Early Warning Line that stretches across the northern rim of North America. Winterized construction equipment powered by diesels is also in use. Most of the DEW Line apparently will be some 200 miles above the Arctic Circle. The Sno-Freighter, especially built for cargo carrying in the Arctic, is the largest rubber tired vehicle. It is 274 ft. long, 12-⅓ ft. wide, made up in six sections, and has 24 tires. Power is supplied by two 400 h.p. diesels coupled to AC and DC 150 KW generator. Each wheel is driven by an electric motor and gear inside the rim. Each of the five cargo carriers has a 25 ton freight capacity; operating temperatures range between 30 and 50 degrees below zero. Special features of design include: extra wide base tires for flotation over snow; aluminum construction where practicable in order to reduce weight; thermo-static control of ventilation to the engines.

43-55 "The Strength of Corrugated Plating for Ship's Bulkheads"—J. R. Caldwell. The Shipbuilder and Marine Engine-Builder, August 1955, V. 62, n. 567, pp. 491–498. Corrugated plating has been an important development in watertight bulkhead construction. Tests on corrugated plating as beams under four point loading are described and include: apparatus and testing procedures, description of specimens, theoretical analysis of specimens, results, derivation of geometrical properties and significance of instability. Test information on single corrugations as beams under four point loading includes: apparatus, procedure, specimen description and results. Testing on corrugated bulkheads under water pressure was discussed. It is concluded that the following factors are to be considered when designing bulkheads for maximum economy of material: (1) Pitch of corrugation should be as large as possible; (2) Deep troughs in thin plating is more efficient than a shallow trough of equal section modulus but in thicker plating; (3) Rectangular profile is more efficient than a trapezoidal or triangular profile of equal section modulus; (4) Items (2) and (3) above hold only if trough dimensions are such that appropriate stability conditions of equation (10) of text is satisfied. Aluminum-alloy corrugated plating represents, theoretically, the most efficient material for transverse watertight bulkheads to resist lateral pressure. Tables, equations, and curves included.

44-55 "Design Features of Fast Patrol Boats"—The Motor Ship, V. XXXVI, n. 425, August 1955, pp. 208–209. H.M.S. "Dark Aggressor," a new

class of fast patrol boat, is powered by two Napier-Deltic engines. This engine is a compact high speed unit of the opposed piston type, with the 18 cylinders arranged in three banks to form in section an equilateral triangle. Weight of each engine and its reverse gear is 10,500 lb. or 4.2 lb./s.h.p. The "Dark Aggressor" is the first of 17 vessels.

45-55 "Combustion in Large Diesel Engines"—P. Jackson. The problem of combustion in large diesel engines is discussed in various phases. The paper covers: fuels, combustion, thermal cycles, engine development, marine engines in large sizes, injection, characteristics of direct-injection combustion chamber, influence of operating conditions on combustion factors, supercharging, maximum pressures, heavy fuels, and economy. It concludes that the savings in fuel costs, by using boiler oils of up to 2500 sec. viscosity, outweigh the occasional troubles and increased wear. Tables, illustrations, curves, and indicator diagrams are included. Photographs include: carbon particles deposited on combustion chamber test pieces, electron micrograph of deposit, sludge around air ports, corroded journal, corroded crosshead pin and rod, and jets in pressure bomb.

46-55 "Combustion in Diesel Engines with Divided Combustion Chambers" —Introduction by S. J. Davies; Part I by H. Hoffmann: Part II by H. Lang; Part III by O. Cordier.

Part I—Combustion in pre-combustion chamber engines. Data presented under Part I includes: arrangement and types of pre-combustion chambers; results with various types; and development of the combustion process. Combustion in diesels with divided combustion chambers is more complex than engines with direct injection. Many factors exist for favorably influencing the combustion process.

Part II—The Lanova Combustion Process, a Brief Description of its Development and Function. Discussion includes: piston combustion shapes, tests, ignition and combustion in Lanova diesel engine.

Part III—Design Notes on Swirl Chamber Engines. Kinetic energy of compression air, design features, swirl-chamber inserts, design of transfer passage and test results are presented. Considerable care is required in design of swirl-chamber engines to avoid hydraulic losses and to maintain close control of flow conditions in the cylinder. Curves, diagrams and references.

47-55 "B.S.R.A. Resistance Experiments on the *Lucy Ashton*"—S. Livingston Smith. The Shipbuilder and Marine Engine Builder, V. 62, n. 565, June 1955, pp. 371–376. Part IV is presented and concludes the results of investigation. Resistance tests were conducted in the fouled condition. Fouling included grasses and shells. Conclusions of the tests are presented. These accurate full scale measurements of ship resistance were made with aircraft jet engines as propulsion means. It is considered this method is superior to towing. Tests show the following: (1) Fairing seams reduced total resistance approximately 3 percent; (2) painting the hull with smooth bituminous aluminum paint reduced resistance 3 percent under the read lead painting. Tabulated data and curves are included.

48-55 "Fire Appliances"—G. Keenan. The Institute of Marine Engineers Transactions, V. LXVII, n. 6, June 1955, pp. 209–222. Shipboard fire propagation, detection and extinguishing are discussed. Cooling techniques, effect of loose water on stability are presented. Sprinkler systems, oil fires, fire pump performance, hoses, nozzles, emergency fire pumps, foam and foam applications, fixed foam systems, mechanical systems, foam for uptake fires, fires in cargo spaces, diagrammatic layouts, smoke detection, steam smothering and preventative measures in design are included. Trained fire fighting teams are necessary to use orthodox methods while fixed systems are effective with a minimum of trained people.

49-55 "Clark Builds Mobile Gas Turbine Power Plant"—Michael T. Pate. Diesel Progress, Sept., 1955, pp. 50–52. A mobile gas turbine driven generator plant has recently been completed for the U. S. Navy Bureau of Yards and Docks. The gas turbine develops 8,000 hp, is a simple open cycle, non-regenerative, dual shaft, series-flow type. Output is rated at 80°F ambient at altitudes up to 1,000 ft. The turbine consists of an axial flow 13 stage compressor with a 4.25 pressure ratio, an axial flow two stage compressor turbine and a single stage power output turbine. The power output turbine rotates at 3600 rpm and is direct connected to the generator. Normal inlet temperature is 1350°F. All bearings are radial type of babbitt with bronze backing. The generator is rated 5500 kw, 3600/3000 rpm, 60/50 cycle, 12,500 volts, 80% power factor, 3 phase, 40°C ambient. The generator is completely enclosed and is self ventilated. The complete unit will be mounted on a special railway car and will be suitable to supply emergency power in disaster areas.

50-55 "The Successful Burning of Residual Oils"—Diesel Progress, Sept., 1955, pp. 40–42. The data presented is taken from Chapter 10 of the Diesel Engine Manufacturers' Association "Standard Practices." A typical piping diagram for a residual fuel oil system is described. Comments on residual fuel specification data includes gravity, viscosity, sulphur and its effect on engine wear, ash after centrifuging, flash, vanadium, handling and use.

51-55 "The Technical Training of the Marine Engineer Officer"—W. N. Serjeant. The Institute of Marine Engineers Transactions, V. LXVII, n. 6, June 1955, pp. iii-viii. The marine engineer's training should include work in the sciences as well as practical experience. Increasing complexity and cost of propulsion and auxiliary machinery make it essential that the marine engineer be well trained. Methods of training engineering officers under the present systems are outlined. Suggestions for improving the training program include: at least four years of carefully planned workshop with experience on machine tools, welding, tube expanding and other equipments; attendance of part time day classes or full time courses on the sandwich system; minimum sea time extended from eighteen to twenty one months.

52-55 "The Significance of Microhardness Testing"—A. P. Miodownik. The Journal of the Institute of Metals, V. 2, n. 22, June 1955, pp. 258–261. Microhardness testing is used in fields where small parts such as watch parts, foil and electro plated specimens are encountered. It has been extended into research fields where hardness variations in single crystals are measured. The deviations and scatter found in these measurements are studied. Material includes: types of low-load hardness deviations encountered in microhardness testing; deviations attributable to instrument construction and specimens; and applications of microhardness testing. This method of testing is used as a method of control. It is dependent on the applied load. It is more difficult to use than the microhardness but reveals more information about metal structure.

53-55 "Some Physical Aspects of Lubrication in Rolling Bearings and Gears" —W. Lewicki. The Engineer, Part I V. 200, n. 5193, 5 Aug. 1955, pp. 176–178, Part II V. 200, n. 5194, 12 Aug., 1955, pp. 212–215. Theoretical and experimental work on the rolling-contact mode of lubrication is presented. The purpose of the work described was to measure film thickness. Film thickness determination methods are presented. They include ohmic resistance, inductive capacitance and residual capacitance methods. Air bubbles and their effects are described. Test apparatus, procedures and results are presented. Material includes diagrams, curves, literature review and references.

54-55 "Shaft Finish—Its Relationship to Sleeve Bearing Life"—J. B. Mohler, Machine Design, V 27, n. 7, July 1955, pp. 132–136. The surface roughness of a shaft can have a direct bearing on bearing life. Roughness of a bearing is generally a temporary condition and will smooth out with operation. Conditions contributing to localized loading can overshadow surface finish. These include: excessive crush, loose bearings, out of round, misalignment, edge loading, misplaced housing, improper clearance, housing yield, tapered bore and flat, barrel-shape and hour-glass journal. Laboratory tests to determine seizure with various conditions of bearing and shaft are difficult to reproduce. Consistent seizure test results have been attained by injecting controlled amounts of grit. In this way synthetic means of producing consistent roughness is feasible. Shaft bearing applications are classified as mild, intermediate and severe. Mild applications use babbitts and finish is not so critical. Intermediate applications require aluminum alloys that have some of bronze's load capacity characteristics. Aluminum alloys tend to weld to steel under certain conditions. For these conditions surface finish is more critical than for lower melting alloys. Bronzes, of copper and tin with little or no lead, seize at high speeds, regardless of finish and are usually used for high loads and low speeds. Silver alloys are suited, are similar and are only used in high-load high-speed applications with lead alloy overlays. Shaft finishing methods include vapor blast, electro-chemical methods, electro polishing and periodic reverse plating. Photographs, sketches, references.

55-55 "Welding Comes of Age—New Applications"—John L. Lang, Mechanical Engineering, V. 77, n. 9, Sept., 1955, pp. 782–784. New developments in welding equipment and techniques are playing an important part in applications of new metals and alloys. Manual shielded metal-arc welding process is an arc welding process wherein coalescence is produced by heating with an electric arc between a covered metal electrode and work with decomposition of the electrode covering giving the shield. Submerged-arc welding is a process where coalescence is produced by heating with electric arc between a bare metal electrode and the work. Inert-gas, shielded-metal-arc, nonconsumable-electrode uses an inert and a tungsten electrode. Filler metal is fed into the arc or the joint is such that edges are melted down. In the inert-gas, shielded-metal-arc, consumable-electrode process the electrode is fed into the arc mechanically and serves as filler metal. Spot, seam, projection and flash welding are described. New iron-powder-type electrodes will be important in the future. New metals and alloys can be welded into intricate forms by these welding methods. Automatic welding will play an important part in new production techniques.

56-55 "Combustion of Residual Fuel in Gas Turbines"—P. T. Sulzer and I. G. Bowen. Experience with combustion of residual fuels in the 20,000 kw semi-closed cycle plant at Weinfelden and the tanker *Auris* is presented. The mechanism of deposition and corrosion is described. Operation at Weinfelden with additives in fuel lead to these conclusions: (1) corrosion of air-heater tubes can be overcome, though powder like layer forms in the tubes and must be cleaned; (2) slight deposits occur on blades at high pressure and remain constant after short period; (3) fuels with high sodium may require washing and centrifuging. The *Auris* experience showed: (1) deposits spall off after shut down and thus relieve some of the deposition problem; (2) ash deposition rate was greatly accelerated when there was no smoke or solids in the gases; (3) aluminum silicate was effective in inhibiting deposition; (4) ethyl silicate was effective but gave trouble due to hydrolysis; (5) magnesium was ineffective in reducing deposition. Tables, curves, diagrams and references.

57-55 "Computer-Controlled Machine Tools"—D. T. N. Williamson. The Engineer, V. 200, n. 5192, 29 July 1955, pp. 151–153. Use of digital computers can be of value in the control of metal cutting processes where small quantity production is involved. A system for utilizing modern techniques of computation and control consists of: (1) transfer of drawing information and machining data to a standard planning sheet; (2) coding of the planning sheet on a punched paper tape; (3) production from this tape of a recorded magnetic tape by means of a digital computer; (4) use of the magnetic tape to control the machining operation. Economics of the computer-controlled machine tool operation may be difficult to determine. An example of gain in speed of tool making is: a three dimensional cam that requires three weeks to produce by usual methods can be planned, computed and machined in

four hours. Computer-controlled machines can reduce production times by large amounts. Digital computers may eventually have far reaching affects on production techniques.

58-55 "The Surface Condenser"—J. R. Spencer; Westinghouse Engineer, V. 15, n. 4, July 1955, pp. 121–125. First radial-flow surface condenser was built in 1911 by Westinghouse. Continued improvements have been made. Condensers now capable of producing condensate of a quality that no additional treatment is required such as deaerating heaters and chemicals. Radial-flow unit can produce condensate with a maximum oxygen content of 0.01 cc. per liter. Moments on turbine resulting from condenser must be considered. Feed water heaters in steam inlet to large condensers, over 40,000 square feet of heating surface, have value in some cases. Transportation of complete units of cylindrical construction is limited to 15,000 to 20,000 square feet of surface. Trend in new designs is to rectangular construction and vertical, pit-type pumps to save overhead space which is usually critical. New developments in progress include: increased thermal effectiveness of condenser tubes, tube arrangements, improved baffling, improved dropwise condensation, greater water velocities than seven to eight feet per second and new tube materials.

59-55 "Fuel and Lubricant Treatment by Centrifuge"—C. L. Bailey. The Marine Engineer and Naval Architect, V. 78, n. 944, July 1955, pp. 269–272. Principles of operation, separation procedure and factors influencing performance are presented. Methods of evaluating performance of purifiers and clarifiers are discussed. For a series arrangement of purifier/clarifier that is operating properly the weight ratio of purifier to clarifier deposits should generally exceed 3:1. Ash reduction of 0.01 percent by weight has reduced liner wear by 50 percent. Purifiers are effective with water washing in reducing water content, insoluble matter and oil acidity in non-additive lubricating oil and in this way reduce chances of corrosion in diesel engines. Oils with additives can be centrifuged.

60-55 "Jet Noise"—F. B. Greatex. The Engineer, Part I, V. 200, n. 5188, 1 July 1955, pp. 23–25; Part II, V. 200, n. 5189, pp. 45–47; Part III, V. 200, n. 5190, pp. 92–93. Noise generated by various jet and piston engines has been measured and analysed. Most of jet noise results from turbulent mixing of high velocity gases with the surrounding air. Noise was studied during ground running and while passing overhead during take-off and approach. Noise from ground running could be effectively silenced by a ground muffler. Maximum values of total noise for several aircraft during take-off are:

Comet	106	decibels
Constellation	102.5	"
Stratocruiser	99	"
Viscount	94	"

Passengers in jet-engined airliners will not likely be affected by jet noise since it is only a problem at take-off.

61-55 "Instruments as Applied to Detection of Flame Failure"—W. D. Stevens. Flame failure detection equipment is in wide demand for use with centralized and automatic controls on boilers and other combustion equipment. Television equipment is used to relay a visual picture of the flame to a desired point. Another general type of equipment includes those devices that can detect the presence, absence or relative strength of a flame and transmit this information into an alarm or fuel shut-off. Detecting devices employ sensitive elements such as: stack temperature element, photo-electric cell, flame rod, lead sulfide cell and combustible analyzer. These sensitive elements can be arranged in applications to suit oil and gas burners. Electrical systems can be such that a complete arrangement would be entirely automatic. Illustrations include: arrangements of scanners for oil and gas fired installations.

BOOK REVIEW

HANDBOOK OF ENGINEERING MATERIALS

Edited by DOUGLAS F. MINER and JOHN B. SEASTONE

Published in 1955

John Wiley and Sons, Inc.

440 Fourth Avenue, New York 16, N.Y.

1362 pages with Illustrations

Price $17.50

Reviewed by Asst. Prof. Leonard R. Mann

Department of Marine Engineering

United States Naval Academy

In this age of new materials, as well as revamped common materials, a new handbook in the field of engineering materials is as welcome as an extra consultant.

With the engineer dependent on intelligent selection of materials, methods of taking advantage of their natural characteristics, appearance factors for consumer products, ease of fabrication, availability and cost, the complex problem of selection of materials must be approached with caution.

Often, data on commonly used materials cannot readily be located. This Handbook of Engineering Materials is designed to meet this need, chiefly among engineers, for a single source of authentic and useful information on the usual materials of manufacturing and construction. At the expense of being something less than all-inclusive or exhaustive in any given area of technical information, the present Handbook presents sufficient data to form a useful guide to the selection of a wide range of materials and suggests sources of more complete information. In scope it is more complete than a technical dictionary but less detailed than special textbooks. Historical background and methods of manufacture have generally been omitted because they are not of prime interest to the user of materials.

The Handbook has been arranged by classes of related or similar materials. For example, metals are in one section, fabrics in another. This permits ready comparison of materials that are competitive. The designer or user frequently

has to make a choice—stainless steel vs. aluminum, thermoplasic vs. thermosetting plastic, etc. Such a choice must be based on an adequate knowledge of properties as well as costs. The present grouping facilitates such an analysis preparatory to a decision.

The Handbook has been compiled at a professional level understandable to engineering designers of products or construction projects, research workers, and advanced students. It is not intended for the general public, because it assumes basic technical knowledge and vocabulary covering units of measurement, methods of calculations, and types of graphic representation.

The reader will find this Handbook adequate and accurate with respect both to materials already familiar and to those unfamiliar to him. The editors, having had long experience in the development and application of engineering materials, have collected the sort of information they and their associates found most often needed and used. Specifically, this book is divided up into four sections. Section 1 covers the field of general information on materials including a brief treatment of specifications and standards, and a new section on statistics in the application of materials. This section also includes a very complete set of mathematical and physical tables. Sections 2 and 3 cover the fields of metals and nonmetals, respectively. Section 4 covers the field of construction materials including a splendid coverage of the subjects of weather and moisture protection.

The Handbook is completely referenced, well-indexed, and should prove a valuable aid in providing information in allied fields.

BOOK NOTICE

ELECTRO-MAGNETIC MACHINES

By R. Langlois-Berthelot

Published in 1955

Philosophical Library, Inc.

15 East 40th Street, New York 16, N.Y.

535 pages. $15.00

The author of this book, which was first published in France, is the Chief Research Engineer for Production and Transformer Equipment at "L'Electricité de France" and Professor of Electrical Engineering at L'Ecole Supérieure de Paris.

C. W. Marshall, of the British Electricity Authority, states in his Foreword to this book, ". . . this book is unique in respect to its objectivity, in excluding as far as is practicable everything that is transitory and in retaining what appears to be permanent. It is thus a happy mean between the classical French treatise

which tends to exclude everything which savors of practice, and the materialistic English type which concentrates on what is for the time being practical and utilitarian."

The book is in six parts. Part One deals with the various families of machines, reviewing their main properties and applications in the industry. Part Two covers the general anatomy and physiology of electrical machines. Part Three deals with the machine as seen by the designer, and Part Four as seen by the engineer or user. Part Five covers abnormal conditions of operation, while Part Six contains miscellaneous general comments.

BOOK NOTICE

MAGNETIC MATERIALS IN THE ELECTRICAL INDUSTRY

By P. R. Bardell

Published in 1955

Philosophical Library, Inc.

15 East 40th Street, New York 16, N.Y.

288 pages. $10.00

This book is intended to be helpful to senior students in physics and electrical engineering and to physicists and engineers in industry, by providing a better understanding of the properties of the large number of magnetic materials now available. Apart from the rather difficult nature of the subject the position is obscured by the camouflage of proprietary names under which the identity of commercially available materials is hidden. The use of a wide variety of terms and units is another source of complexity.

An attempt has been made to resolve some of these difficulties by including a glossary of terms and units, by the provision of tables showing the properties of materials and by a note explaining magnetic terminology and units.

After a discussion of the influence of magnetic theory on the development of materials in Chapter 2 subsequent chapters deal with the historical development, application and testing of permanent magnets and of soft magnetic materials. Further chapters are devoted to special devices such as sound recorders, non-destructive tests, transductors and transducers.

BOOK NOTICE

THE MOBILE MANUAL FOR RADIO AMATEURS

Published in 1955

The American Radio Relay League, Inc.

West Hartford 7, Conn.

352 pages. $2.50

This book is a useful guide to an increasingly popular amateur activity, mobile radio. It contains a section on receiving, with valuable information on automotive noise suppression; a group of articles describing over 30 different mobile transmitters; sections on mobile antennas and power supplies and excerpts from the Federal Communications Commission's regulations governing mobile operation. Also included is a catalog of mobile equipment, along with other radio equipment produced by well-known firms in the electronics industry.

BOOK NOTICE

LAPLACE TRANSFORMS FOR ELECTRICAL ENGINEERS

By B. J. STARKEY

Published in 1955

Philosophical Library, Inc.

15 East 40th Street, New York 16, N.Y.

279 pages. $10.00

The method of solving linear differential equations, originally published by Laplace, has been in use by mathematicians for well over a century, but only in recent years have engineers begun to realize its usefulness to them. The Laplace transformation theory is extremely helpful in providing quick solutions to a great range of engineering and physical problems and often saves many laborious calculations required by other methods.

Normally, the language used by mathematicians to present the theory is rather difficult for the engineer, whose knowledge of higher mathematics may not go beyond differential and integral calculus, theories of complex numbers and vector analysis. In this book the language used is well known to engineers in general, and the method of explaining the problems is particularly familiar to electrical engineers.

BOOK NOTICE

ELECTRO-TECHNOLOGY

By M. G. SAY

Published in 1955

Philosophical Library, Inc.

15 East 40th Street, New York 16, N.Y.

167 pages. $6.00

This book presents in concentrated form the electro-technical basis of the phenomena which are important in electrical engineering.

The first section deals with conduction and magnetic and electric field effects, and a comprehensive list of definitions is given. The second section gives a complete guide to the handling of circuit problems. Two-terminal and four-terminal cases are dealt with, and balanced and unbalanced three-phase circuits. A feature is the collection of net work theorems, which should be of help to those who have to work out electrical quantities in all types of circuits and networks.

BOOK NOTICE

DICTIONARY OF MECHANICAL ENGINEERING TERMS

Originally compiled by J. G. HORNER

Seventh Edition revised by STATON ABBEY

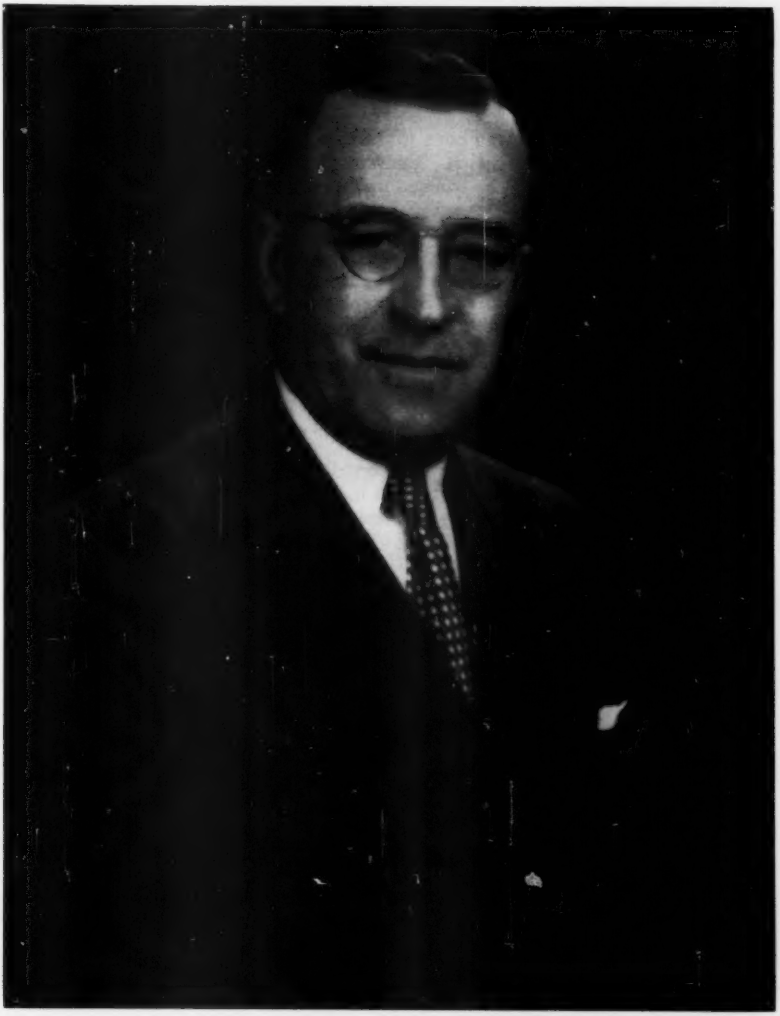
Published in 1955

Philosophical Library, Inc.

15 East 40th Street, New York 16, N.Y.

417 pages. $6.50

This Seventh Edition is completely revised and greatly enlarged by the inclusion of terms which have come into use during recent years. The book is divided into two parts, the first dealing with modern terms and the second dealing with general and traditional terms.



MR. EDWARD C. MAGDEBURGER

Mr. Edward C. Magdeburger

The Society regrets to announce the death on 11 October 1955, of Mr. Edward C. Magdeburger, a distinguished Civil Member, at the age of 69 years, from a heart condition with which he had suffered since June, 1955.

Mr. Magdeburger was born in Tanbov, Russia. He was graduated from the University of St. Petersburg in Russia. Coming to the United States in 1911, he worked in New York and Milwaukee. Later he was associated with Busch-Sulzer in St. Louis, Mo., and was chief engineer of St. Mary's Oil Engine Co. in St. Charles, Mo. He came to Washington, D.C., in 1922 under an appointment by President Harding as Aide on diesel engines in the Bureau of Ships, Navy Department. He was Director of Special Developments in the Internal Combustion Section of the Bureau when he retired, in 1953.

Mr. Magdeburger joined the Society in 1925, and was an active member until his death, contributing many articles to the JOURNAL. On 4 October, 1955, he was nominated for Honorary Membership with the following citation:

> "In view of his considerable contribution in the diesel engine field, his leadership and vigor in the adoption and use of diesel engines by the U.S. Navy, his inspiration and guidance to the many Naval Engineers and young officers who worked with him, and his outstanding performance as a good citizen, the Council of the American Society of Naval Engineers takes great pleasure in directing that Mr. Edward C. Magdeburger's name be printed on the ballot for the 1956 election of officers with recommendation for election as an Honorary Member."

His name was before the Society for election to Honorary Membership at the time of his death.

In addition to his membership in this Society, Mr. Magdeburger was a member of the American Society of Mechanical Engineers, which last spring also honored him for his contribution in the diesel field.

He was active in fraternal circles and was an elder in the Sixth Presbyterian Church of Washington.

He is survived by his widow, Elvira Zimmerman Magdeburger, three sons, two daughters, and five grandchildren.

Burial services were held on 13 October, 1955, with interment in Rock Creek Cemetery in Washington.

DIED

It is sincerely regretted that the death of the following since the August, 1955, Journal was published must be recorded:

BURRIS, HARRY, Naval Member

FREAR, Hugo P., Associate Member

MAGDEBURGER, EDWARD C., Civil Member

PICK, ROBERT B., Naval Member

STIVENDER, E. H., Civil Member

CHANGES IN MEMBERSHIP

The Society announces with much pleasure that the following have become members since the publication of the August, 1955, JOURNAL:

NAVAL

Anderson, Charles Harper, Captain, USN, Ret.
Naval Ordnance Dept., General Electric Co.,
100 Plastics Ave., Pittsfield, Mass.

Bucknell, Howard III
USS POMFRET (SS 391) c/o Fleet P.O., San Francisco, Calif.

Eller, Ernest McNeill, Rear Adml., USN, Ret.
Director of Engineering,
Bucknell University, Lewisburg, Penna.

Golly, Robert Dingman, Lieut., USNR,
Rome Cable Corp.,
2510 S. Malt St., Los Angeles 22, Calif.

Hendelman, Teddy S., Lt., USN,
USS PERRY (DD 844), Fleet P.O., New York, N.Y.

Lobkovich, John F., Lt., USCG,
USN Administrative Unit, M.I.T., Cambridge, Mass.

Loeffler, Lawrence Edgar, Lt., USN,
USS PERRY (DD 844), Fleet P.O., New York, N.Y.

MacMath, Warren Elliott, Comdr., USN,
U.S. Naval Boiler & Turbine Laboratory,
Naval Base, Philadelphia, Penna.

Molis, Edward Warner, Lieut., USN,
USS ASKARI (ARL-30),
Fleet P.O., San Francisco, Calif.

Morgan, Philip C. Jr., Commander, USN,
Code 366, Bureau of Ships,
Navy Department, Washington, D.C.

Packer, Francis Avery Jr., Lt. Comdr., USN,
Staff Service, Squadron One, San Diego, Calif.

Smith, John Arthur, Lieut., USN,
Engineer Officer, FORREST SHERMAN (DD 931),
1 Dale Street, P.O. Box 216, Monument Beach, Mass.

Tucker, James Francis, Sr., Capt., USN,
Director of Naval Science Div., Office of Naval Research,
2511 North Vermont Ave., Arlington, Va.

Van Lopik, William P., Lieut., USNR-R,
826 Forest Ave., River Forest, Illinois

CIVIL

Crissinger, Woodrow W.,
Chief Field Engr., Industrial Div. North Electric Co.,
Galion, Ohio

Humphries, Don H.,
Chief Draftsman, Hoffman Laboratories,
4827 6th Ave., Los Angeles, Calif.

Joyce, Harry V.,
Ordnance Metallurgist, U.S. Steel Corp.,
525 William Penn Place, Pittsburgh 30, Penna.

Ryan, Robert Clifton,
Senior Engr., Westinghouse Electric Corp.,
34 Dutch Lane, Pittsburgh 36, Penna.

ASSOCIATE

Bukarin, Alexander Ivanovich, Lieut., USRRN.
2552 Belmont Rd., N.W., Washington, D.C.

Cahoon, Robert L.,
Manager Alloy Plate Sales,
Lukens Steel Co., Coatesville, Penna.

Lovejoy, Lindsey A.,
Atomic Power Equipment, Dept. General Electric,
1296 Lowell Road, Schenectady, 5, N.Y.

Tatton-Brown, Peter D., Comdr., R.N.,
BJSM, P.O. Box 165, Ben Franklin Station, Washington, D.C.

Wheeler, Carlos V.,
Marine Engr., Bureau of Ships,
210 East Broad St., Falls Church, Va.

JUNIOR

Bellinger, Dan E., Ensign USNR,
USS Gross (DE 494)
c/o Fleet P.O., San Francisco, Calif.

REJOINED

FitzGerald, Sydney A., Naval Member, Elect. USNR,
619 SW 2nd Ave., Portland, Oregon

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch (es) of the author (s). 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers
1012 14th St., N. W.
Washington 4, D. C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

PERMISSION TO REPRINT

Permission is granted to reprint any original article contained herein if the following conditions are met:

a) The article is reprinted in full. Extracts or summaries or condensations may be printed with the consent of the author.

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c) Credit is given to the author.

d) If the author is a military officer or a civilian employe of the Department of Defense, the following note shall be carried:

> "The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

SECRETARIES OF THE SOCIETY

Current:

Captain J. E. HAMILTON, U. S. Navy, Retired

Past Secretaries:

1889	P. A. Engineer R. S. GRIFFIN, U. S. Navy
1890	Assistant Engineer W. M. MCFARLAND, U. S. Navy
1891	Assistant Engineer EMIL THEISS, U. S. Navy
1892–93	P. A. Engineer W. M. MCFARLAND, U. S. Navy
1894–95	P. A. Engineer R. S. GRIFFIN, U. S. Navy
1896–97	P. A. Engineer F. C. BIEG, U. S. Navy
1898	P. A. Engineer W. M. MCFARLAND, U. S. Navy
1899	Chief Engineer A. B. WILLITS, U. S. Navy
1900	Lt. Comdr. A. B. WILLITS, U. S. Navy
1901	Lieutenant B. C. BRYAN, U. S. Navy
1902	Lieutenant C. W. DYSON, U. S. Navy
1903	Lt. Comdr. JOHN R. EDWARDS, U. S. Navy
1904	Lieutenant M. E. REED, U. S. Navy
1905	Lieutenant W. W. WHITE, U. S. Navy
1906	Lieutenant C. K. MALLORY, U. S. Navy
1907–08	Lt. Comdr. T. C. FENTON, U. S. Navy
1909–10	Lieutenant H. C. DINGER, U. S. Navy
1911	Commander U. T. HOLMES, U. S. Navy
1912	Lieutenant JOHN HALLIGAN, U. S. Navy Lt. Comdr. E. L. BENNETT, U. S. Navy
1913	Lieutenant O. L. COX, U. S. Navy
1914	Lt. Comdr. H. C. DINGER, U. S. Navy
1915–16	Lieutenant A. T. CHURCH, U. S. Navy
1917	Lt. Comdr. J. O. RICHARDSON, U. S. Navy Lt. Comdr. F. W. STERLING, U. S. Navy, Retired
1918	Lt. Comdr. F. W. STERLING, U. S. Navy, Retired
1919	Lt. Comdr. F. W. STERLING, U. S. Navy, Retired Commander J. S. EVANS, U. S. Navy
1920	Commander J. S. EVANS, U. S. Navy
1921	Commander J. S. EVANS, U. S. Navy Commander S. M. ROBINSON, U. S. Navy
1922–23	Commander S. M. ROBINSON, U. S. Navy
1924–25	Commander BRYSON BRUCE, U. S. Navy
1926	Commander A. M. CHARLTON, U. S. Navy
1927	Commander H. B. HIRD, U. S. Navy
1928	Commander H. B. HIRD, U. S. Navy Captain O. L. COX, U. S. Navy
1929–30	Commander H. T. SMITH, U. S. Navy
1931	Captain O. L. COX, U. S. Navy
1932	Commander H. F. D. DAVIS, U. S. Navy
1933–34	Commander H. B. HIRD, U. S. Navy
1935	Commander C. S. GILLETTE, U. S. Navy
1936	Commander C. S. GILLETTE, U. S. Navy Commander ROGER W. PAINE, U. S. Navy
1937	Commander ROGER W. PAINE, U. S. Navy
1938	Commander ROGER W. PAINE, U. S. Navy Lt. Comdr. GUY CHADWICK, U. S. Navy
1939–40	Lt. Comdr. GUY CHADWICK, U. S. Navy
1940–44	Captain J. E. HAMILTON, U. S. Navy
1945	Commander R. T. SUTHERLAND, JR., U. S. Navy
1945–48	Captain F. W. WALTON, U. S. Navy
1948–51	Captain J. E. HAMILTON, U. S. Navy

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